Engineering the Future

Cell 6

Requirement 4) Visit with an engineer:

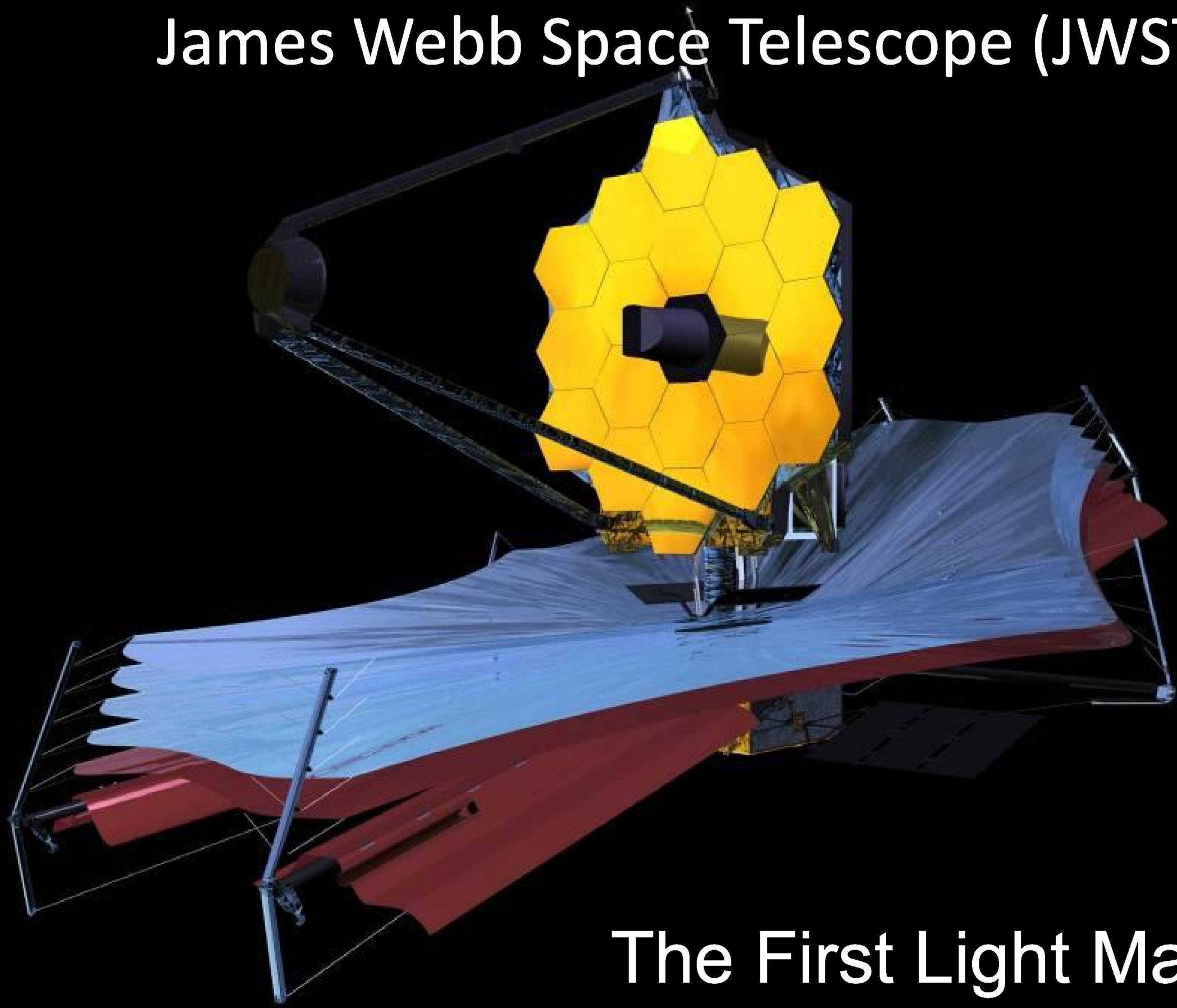
a. Discuss the engineer's work and the tools used.

b. Discuss a current project and the engineer's role.

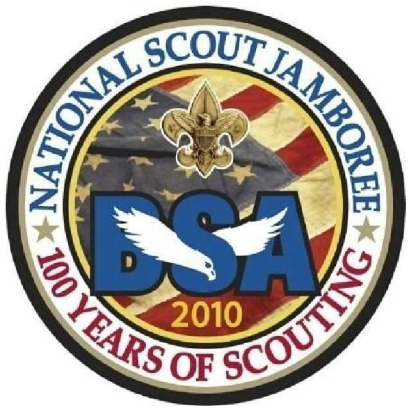
c. Find out how the engineers work is done and how results are achieved.

d. Look at written reports.

James Webb Space Telescope (JWST)



The First Light Machine



Engineering the Future

How to Engineer a Space Telescope

Use a Systems Engineering Methodology

Organize the Project

Engineering Specifications flow from Science Requirements

Plan Activities and Schedule

Preliminary Design & Analysis

Technology Development

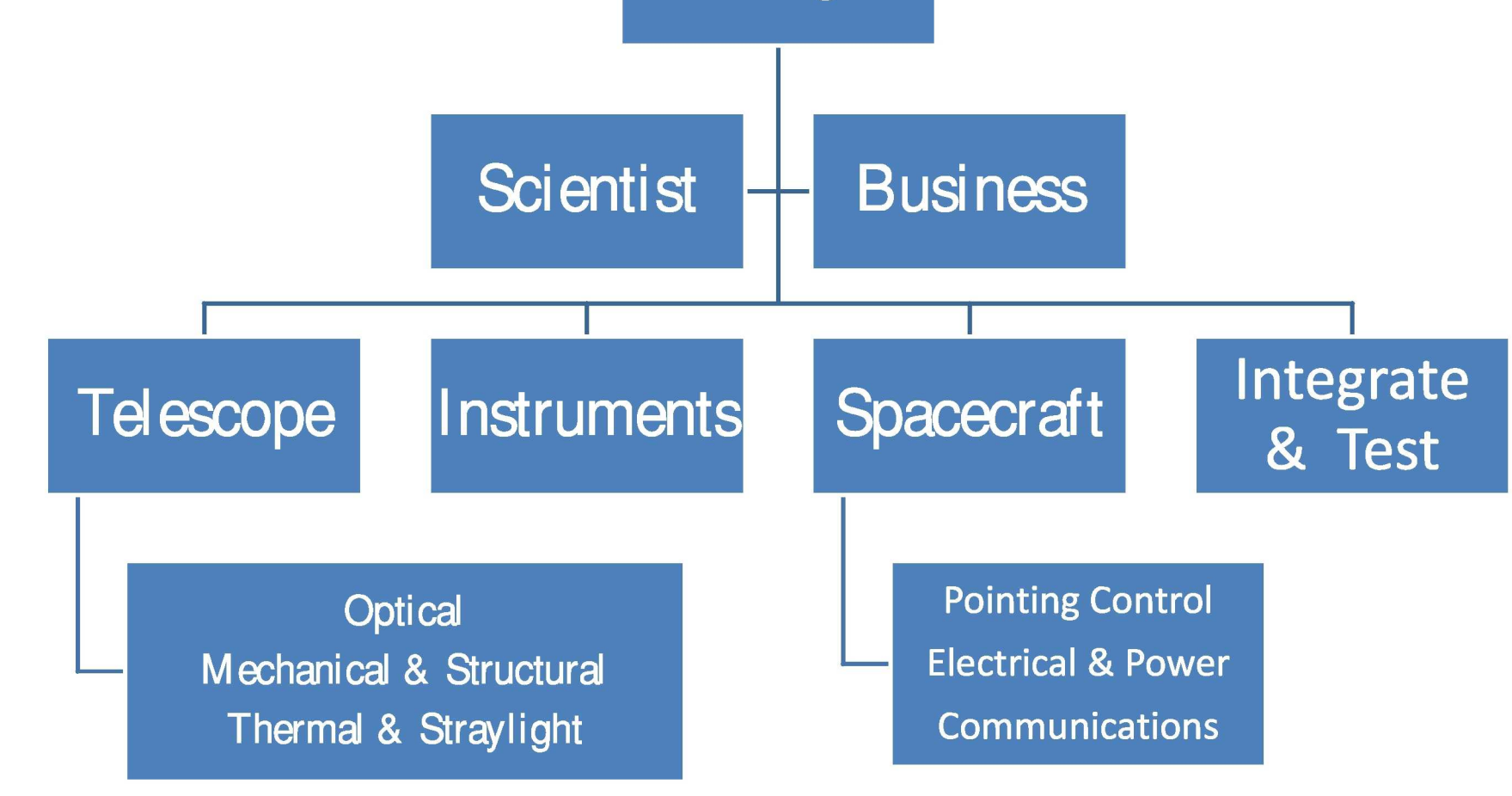
Competition of Designs and Down Select

Engineering Development Units

Verification and Validation by Test and Analysis

Engineering the Future

Organize the Project



James Webb Space Telescope (JWST) Project ± Code 443

JWST-REF-000838
Revision Y

Senior Project Scientist
J. Mather (665)
Deputy Sr Project Scientist
J. Gardner (665)

M. Greenhouse (665) - ISIM Scientist
M. Clampin (667) ± Observatory Scientist
G. Sonneborn (665) ± Operations Scientist
C. Bowers (667) ± Deputy Observatory Scientist
B. Rauscher (665) - Deputy ISIM Scientist

Associate Director
P. Sabelhaus
Deputy Associate Director
J. Decker
Deputy Associate Director / Technical
J. Durning
Business Manager
R. King
Deputy Business Manager
C. Steeley

5□□2¶0DU±DFinancial Mgr
C. McKenzie (210.S) ± Procurement Mgr
J. King (210.S) ± Contracting Officer
D. Miller ± Project Support Mgr
L. Chandler (130) ± Public Affairs

Mission Systems Engineer
M. Menzel (599)
Deputy Mission Sys Eng
M. Davis (Ball)

R. Lynch (599) ± Sys Mgr
R. Sabatino (581) ± F&G SW Sys
G. Mosier (592) ± Integ Modeling
(Acting) K. Parrish (545) ± Therm Sys
J. Lawrence (543) ± Mech Sys
G. Golnik (Schafer) ± Opt Sys
S. Irish (542) ± Structures
(Acting) R. Meloy (Muniz) ± Elec Sys
B. Jeffers (QSS) ± Parts
S. Le (Ball) ± Materials
E. Wooldridge (546) ± Contam

L. Markley (591) ± ACS
P. Maghami (OSC) ± GNC
C. Schiff (595) ± Flt Dyn
K. Mehalick (551) ± Opt Sys
R. Sengupta (Sigma) ± Risk Coord
A. Sherman (SGT) ± Chair, ERB
C. Perrygo (SGT) ± Sunshield
M. Bussman (SGT) ± Rqmts
R. Ivancic (SGT) ± S/C Sys
D. Muheim (592) ± Integ Modeling

Chief Safety and Mission Assurance Officer (CSO)
J. Radich (324)

P. Gibbons (321) ± Project Safety Mg
J. Radich (Acting) (324) ± ISIM CSO

Observatory Manager
P. Geithner
Deputy Obs Mgr
K. Parrish (545)

Obs Scientist
M. Clampin (667)
Deputy Obs Scientist C. Bowers (667)

OTE Manager
L. Feinberg (550)
Deputy OTE Manager
R. Keski-Kuha (551)

Ground Segment & Ops Manager
A. Johns

Operations Scientist
G. Sonneborn (665)

ISIM Manager
J. Dunn
Deputy ISIM Mgr
M. Voyton
ISIM Financial Mgr
C. Doria-Warner

ISIM Scientist
M. Greenhouse (665)
Deputy ISIM Scientist
B. Rauscher (665)

ISIM CSO
J. Radich (Acting) (324)

R. Lynch (599) ± JSC Sys Eng

Observatory Sys Eng
M. Davis (Ball)

Sunshield Manager
K. Parrish (545)

Spacecraft Manager
R. Ivancic (SGT)

J. Allen (DSC) ± S/C Electrical

Cryocooler Manager
M. Larson (JPL)

K. Banks (552) ± Obs Cryocooler SE

Software Manager
R. Sabatino (581)

Observatory I&T Mgr
C. Diaz (Sigma)

Launch Vehicle Liaison
J. Lawrence (543)

W. Hayden (592) ± OTE SE
J. Howard (551) ± Opt. Design Lead
B. Dean (551) ± OTE WFSC Lead
L. Cohen (SAO) ± Mech Sys Lead
K. Thakore (544) ± Electromech Lead

Mission Engineering Manager
J. Gal-Edd (581)

Science Operations Manager
B. Seaton (581)

C. Adams (584) ± FOS Mgr
B. Bruce (441) ± PRD Mgr
R. Detter (594) FITSWriter Mgr
P. Johnson (583) ± PPS Mgr
D. Matusow (581) ± OSS Mgr

Ground Segment I&T Manager
C. Fatig (SAIC)

IGSS Development Manager
J. Steck (583)

A. Bigel (583) ± Dev/Test Eng
T. Pfarr (CSC) ± IGSS Integ. Mgr
E. Woodward (583) - IGSS I&T Mgr.

ICDH Hardware Mgr
Q. Nguyen (561)

G. Henegar (564) IRSU Mgr

ISIM FSW Mgr
B. Savadkin (582)

ISIM Structure Mgr
E. Johnson (543)

R. Rashford (GEC) ± IEC Mgr

OSIM Mgr
T. Pham (556)

Instrument Systems Manager
S. Lambros

ISIM Systems Engineer
R. Lundquist (599)

R. Ohl (Acting) (551) ± Optical Lead
P. Davila (551) ± Optical Sys
J. McCloskey (565) ± Elec Sys
S. Glazer (545) ± Thermal Sys
R. Carter (SGT) ± Mech Sys
J. Johnston (542) ± Str Sys & Int Mod
R. Ladbury (561) - Radiation
S. Le (Ball) ± Materials
R. Perry (SGT) ± Contam
E. Greville (SGT) - FSW Sys
R. Sharma (544) ± Electromech Sys
S. Allen (565) ± Harness
D. Ramey (SGT) ± Ops Lead
K. Barnes (581) - FSW Sys

ISIM I&T Manager
M. Drury (Sigma)

NIRCam Instr Mgr
D. Yun

J. Van Campen (SGT) ± NIRCam ISE

NIRSpec Instr Mgr
T. Johnson (556)

M. Smith (556) ± NIRSpec ISE
R. Estep (556) ± Microshutter SS Mgr
S. Manthripragada (556) ± Detector SS Mgr

MIRI Instr Mgr
P. Driggers (SGT)

C. Aymergen (SGT) ± MIRI ISE

FGS Instr Mgr
S. Lambros

J. Abell (SGT) - FGS ISE

Signature:

Original signed by John E. Decker
3/20/2009

Engineering the Future

Specifications flow from Requirements

Science Requirements	Engineering Specifications
Science Goals	Operating Wavelength
Sensitivity	Aperture Diameter
Exposure Times	Pointing Stability

Operating Wavelength drives:

- Mirror Quality
- Optical Coatings
- Operating Temperature
- Mechanical Stability
- Straylight

Orbit & Launch Vehicle drives:

- Packaging
  - 6.5 m telescope in 4.5 m fairing
- Total Mass
  - 6600 kg to L2
- Structural Launch Survival
  - Vibe & acoustic

Hubble Science Goals

a) Definitively establish the cosmic distance scale (i.e., measure the Hubble constant to 10%)

b) Study galaxy evolution out to z = 1 (this was considered very high redshift back then)

c) Study the intergalactic distribution of gas from quasar absorption lines (required UV coverage)

Required a 2.4 meter diameter, UV/Visible (0.5 micrometer diffraction limited) observatory with milli-arc-second pointing stability and wide field of view.

JWST Science Goals

End of the dark ages: First light and reionization

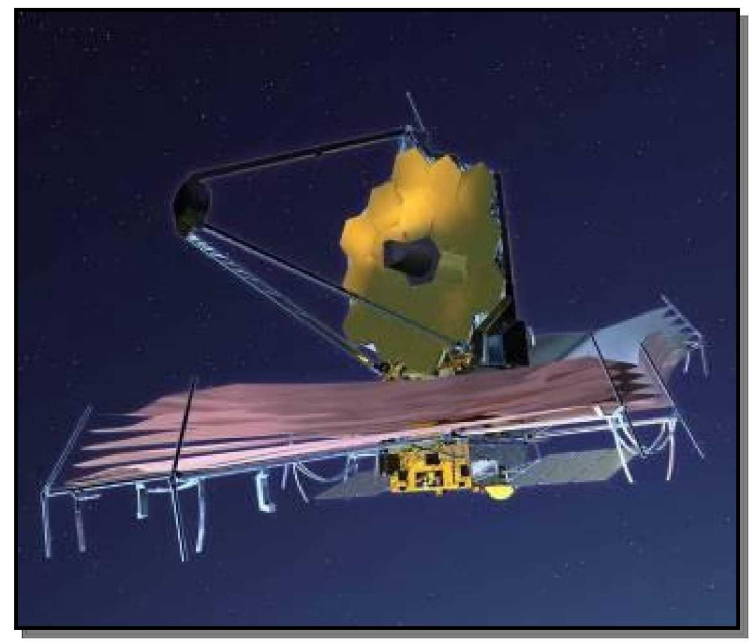
The assembly of galaxies

Birth of stars and proto-planetary systems

Planetary systems and the origin of life

Requires a 6.5 meter diameter, near-infrared (2.0 micrometer diffraction limited) observatory with milli-arc-second pointing stability and wide field of view.

JWST Expands on HST & Spitzer Capabilities

HST	JWST	Spitzer
		
2.4 m Primary	6.5 m Primary	0.85 m Primary
0.5 micrometer	2 micrometer	5 micrometer
Room Temperature	< 50 K (-223C, -370F)	4K

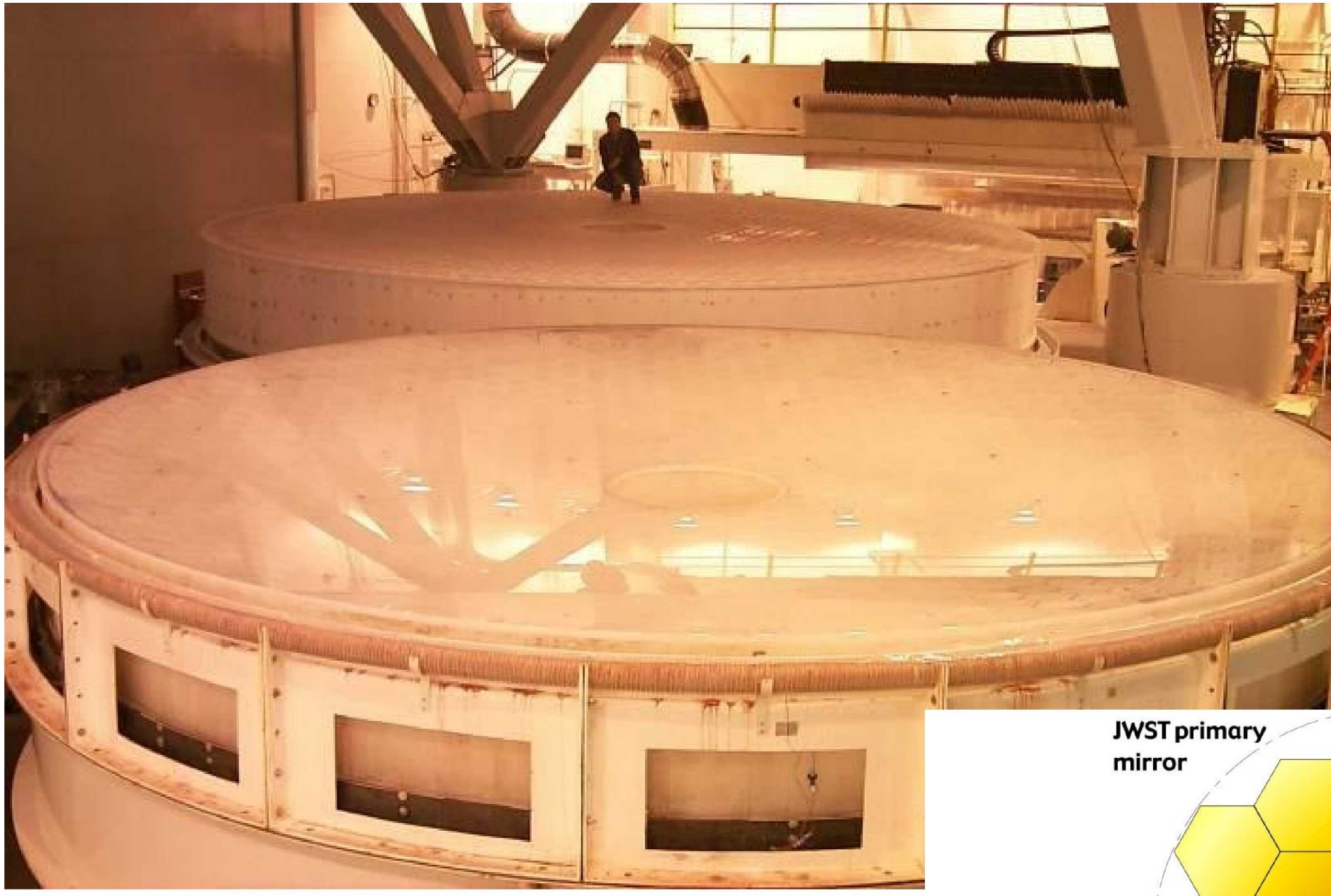
JWST has

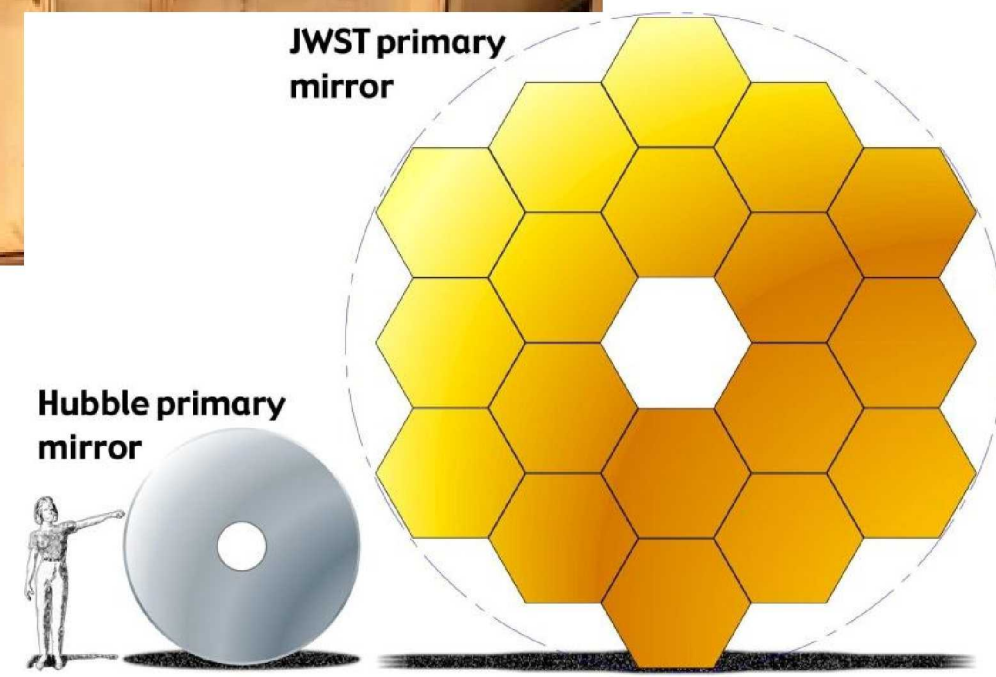
6x the light gathering capability of the Hubble Space Telescope

44x the light gathering capability of the Spitzer Space Telescope

JWST has same angular resolution in the near-IR as HST in visible

How big is JWST?





Full Scale JWST Mockup

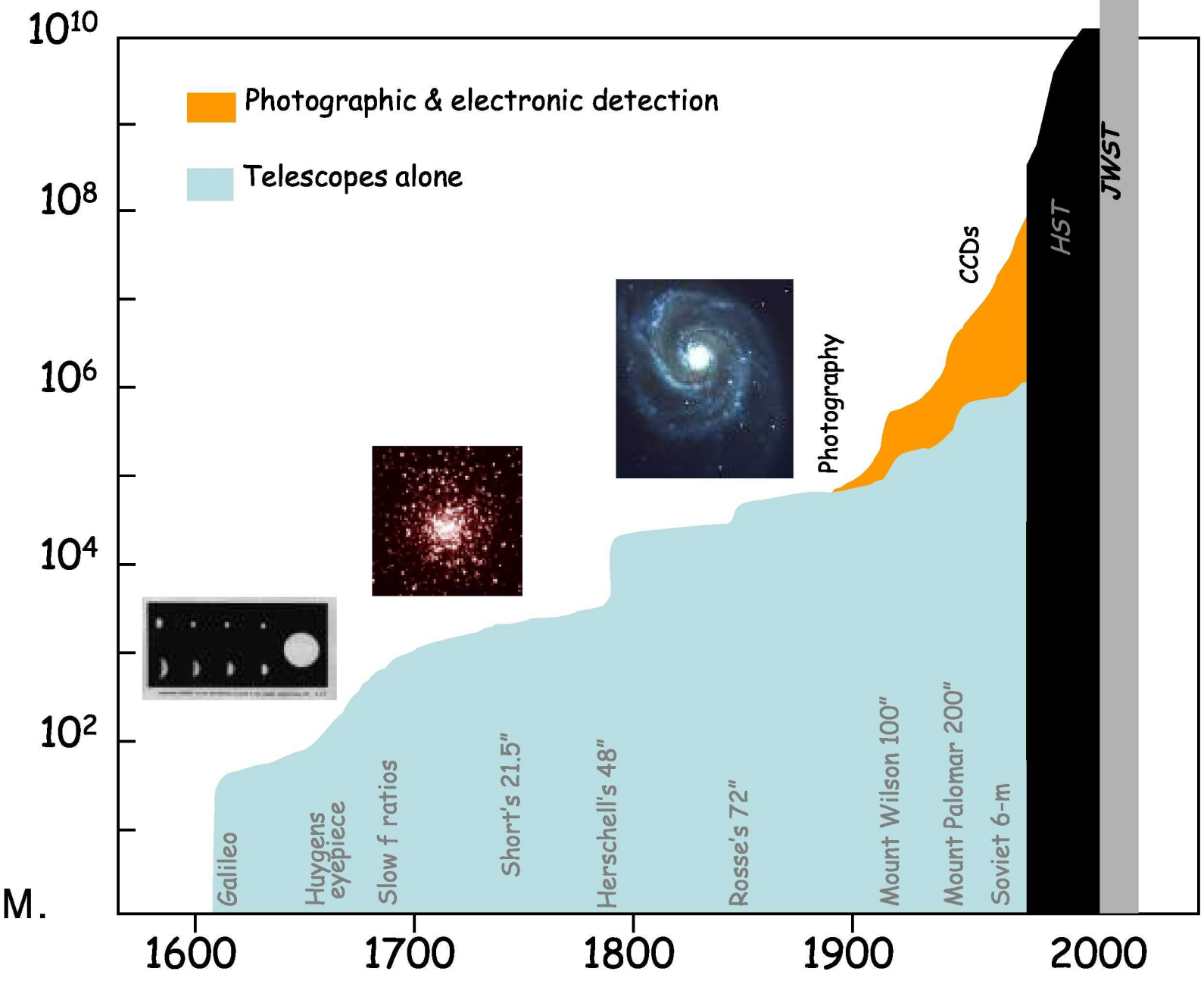
21st National Space Symposium, Colorado Springs, The Space Foundation

How to win at Astronomy

Aperture = Sensitivity

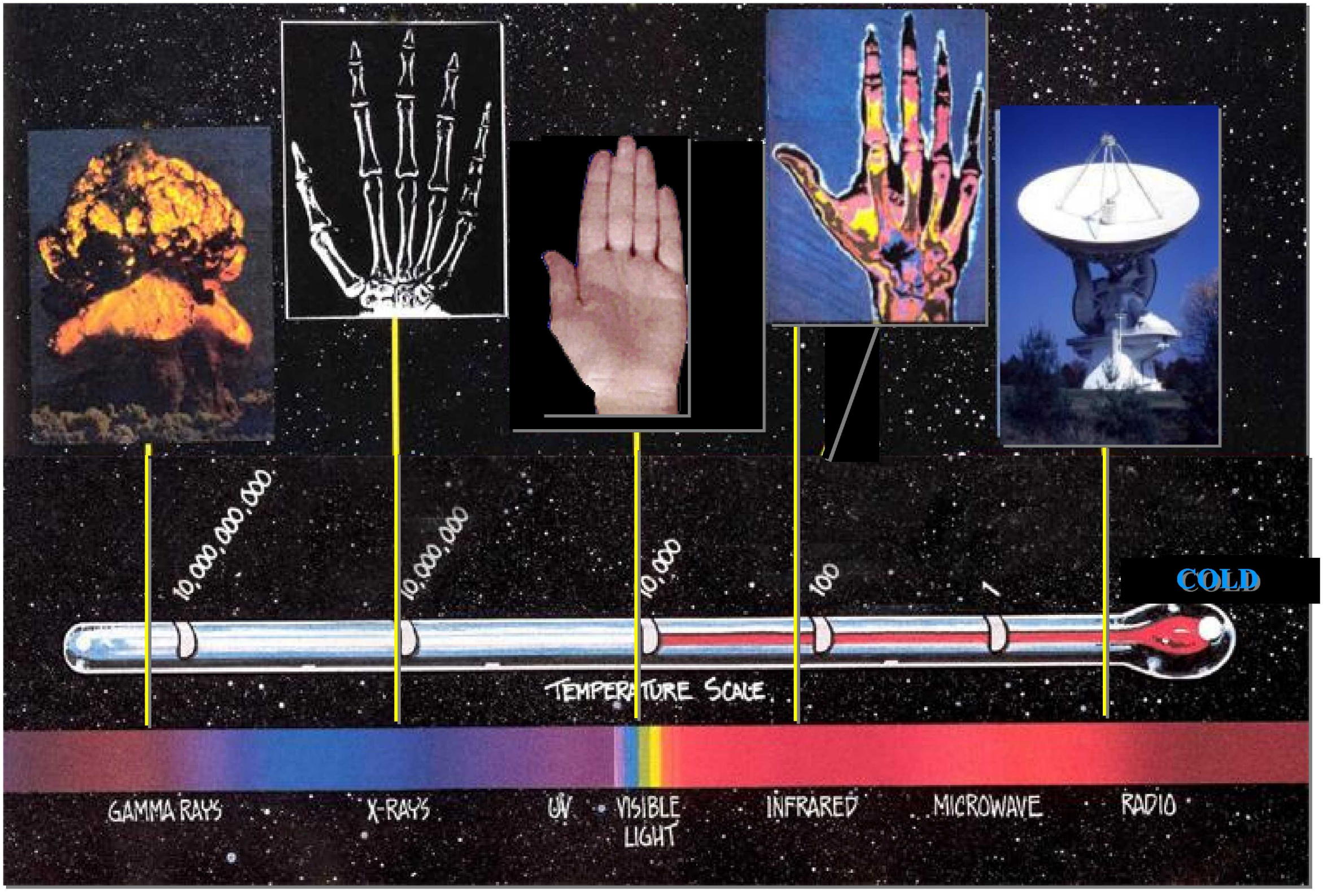
Big Telescopes with Sensitive Detectors In Space

Sensitivity Improvement over the Eye



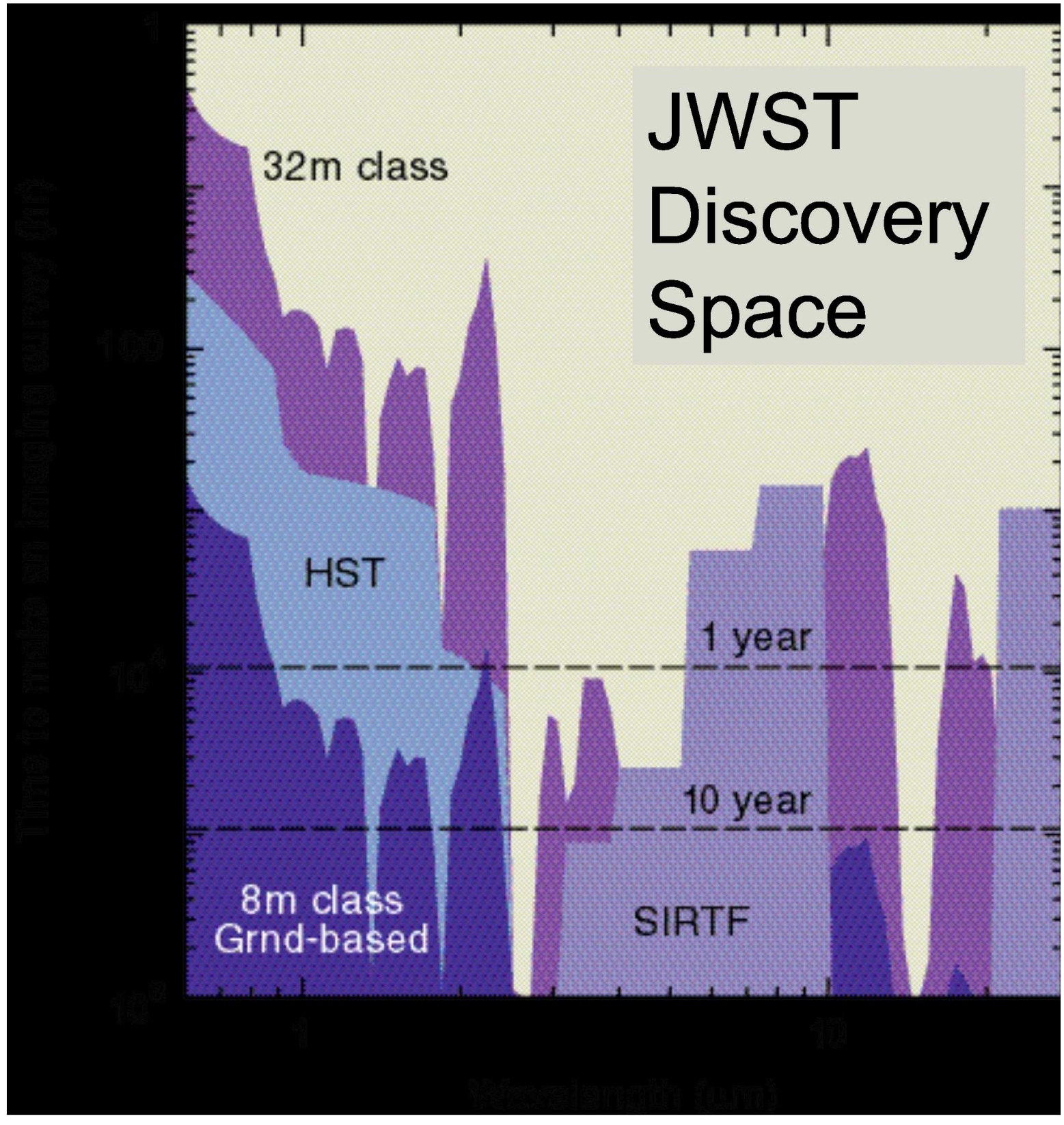
Adapted from *Cosmic Discovery*, M. Harwit

Infrared Light



Why Infrared ?

Why go to Space ± Wavelength Coverage



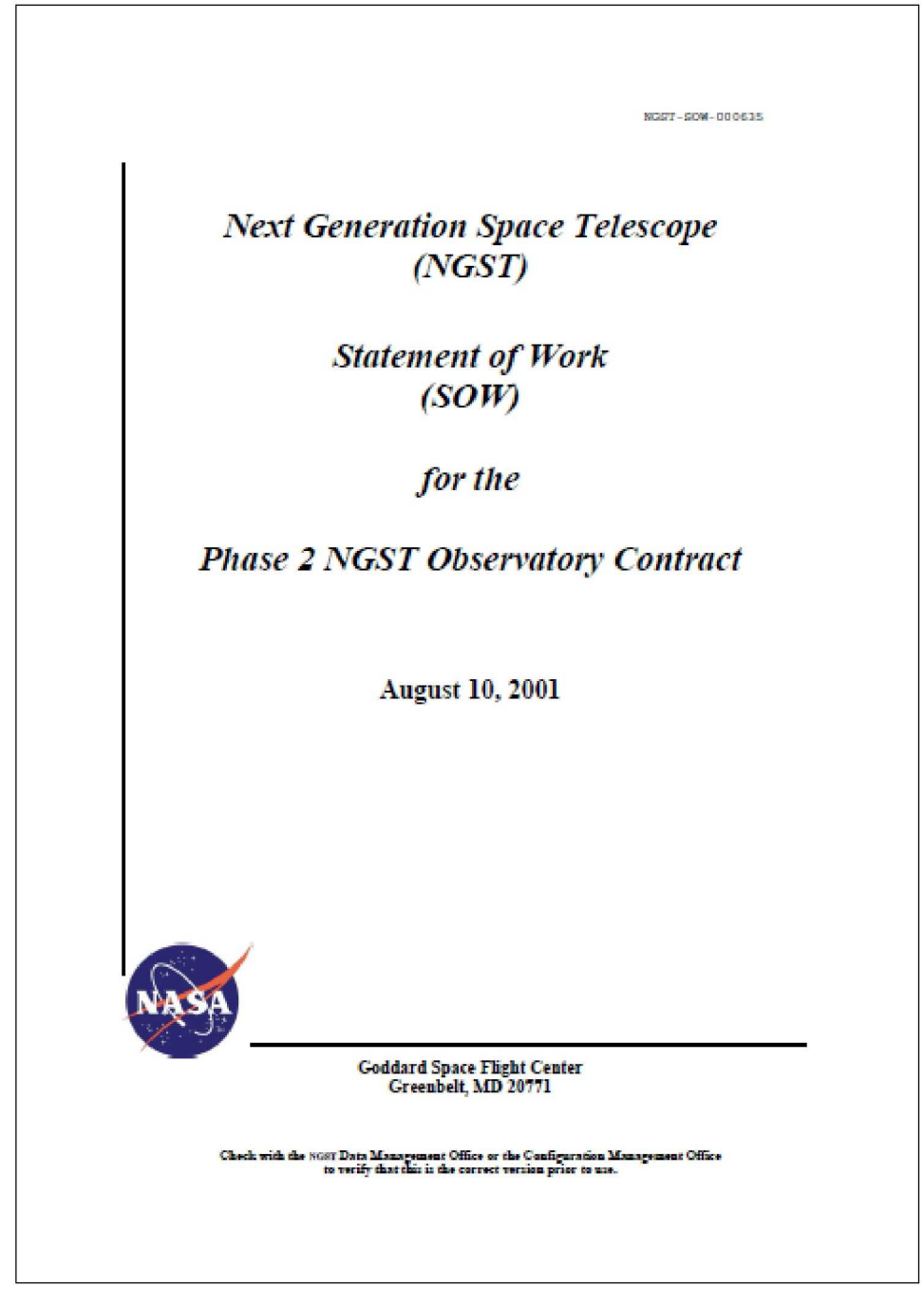
Engineering the Future

Planning

Statement of Work (SOW)

Work Breakdown Schedule (WBS)

Schedule (Gant Chart)



NGST-SOW-000635

Next Generation Space Telescope
(NGST)

Statement of Work
(SOW)

for the

Phase 2 NGST Observatory Contract

August 10, 2001

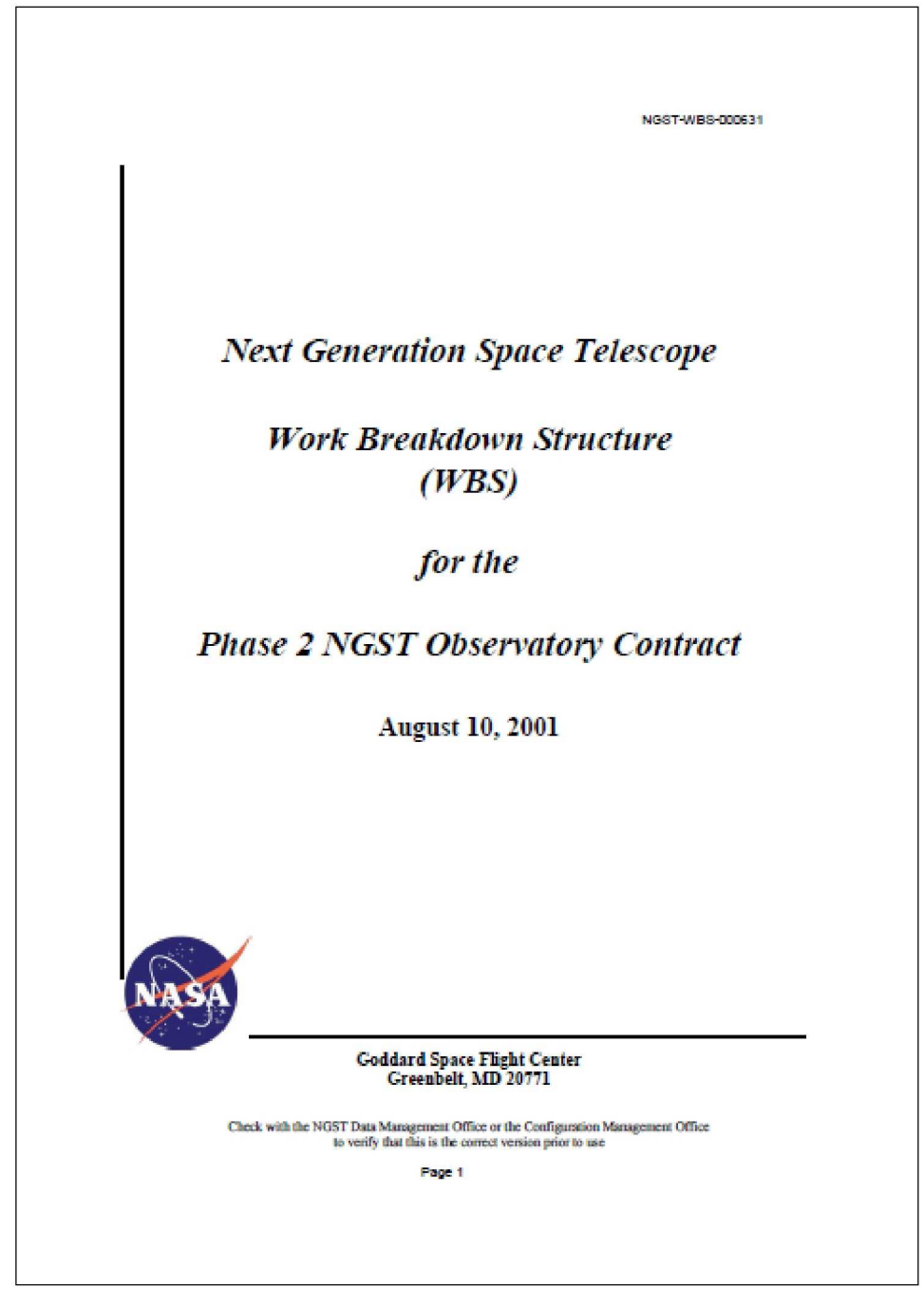
NASA

Goddard Space Flight Center
Greenbelt, MD 20771

Check with the NGST Data Management Office or the Configuration Management Office
to verify that this is the correct version prior to use.

JWST Optical Telescope Element WBS

1. Project Management
2. Reserved
3. Observatory Systems Engineering
   - 3.1 Systems Engineering Management
   - 3.2 Requirement Analysis and Verification
   - 3.3 Interface Management and Configuration Control
   - 3.4 Trade Studies and Life Cycle Cost (LCC) Analysis
   - 3.5 Technical Risk Management
   - 3.6 Technology Development and Validation
   - 3.7 Integrated Modeling and Analysis
4. Observatory Integration and Test
5. Optical Telescope Element
   - 5.1 OTE Management
   - 5.2 OTE Systems Engineering
   - 5.3 OTE I&T
   - 5.4 OTE Simulators
   - 5.5 OTE Subsystem Design, Manufacture, Assembly and Test
     - 5.5.1 Primary Mirror
     - 5.5.2 Other Optics and Structure
   - 5.6 Wavefront Sensing and Control (WFS&C)
6. Sunshield
7. Spacecraft
8. Integrated Science Instrument Module (ISIM)
9. Flight Software (FSW) Systems Development
10. Reserved
11. Ground Segment and Operations/Science



NGST-WBS-000631

Next Generation Space Telescope

Work Breakdown Structure
(WBS)

for the

Phase 2 NGST Observatory Contract

August 10, 2001

Goddard Space Flight Center
Greenbelt, MD 20771

Check with the NGST Data Management Office or the Configuration Management Office
to verify that this is the correct version prior to use

Page 1

JWST Optical Telescope Requirements

Requirements

Primary goal is to observe early universe, at an age between 1 million and a few billion years during when the first stars and galaxies began to form. To accomplish this, JWST will be an infrared observatory instrumented for imaging and spectroscopy, diffraction limited at 2μm, with approximately a 0.1 arc–second resolution, nano–Jansky sensitivity, and a large field of view.

Science Mission Lifetime

Science mission lifetime shall be a minimum of five years, with a total mission lifetime goal of ten years.

Wavelength Range

Spectral coverage shall extend from 0.6μm to >10μm.

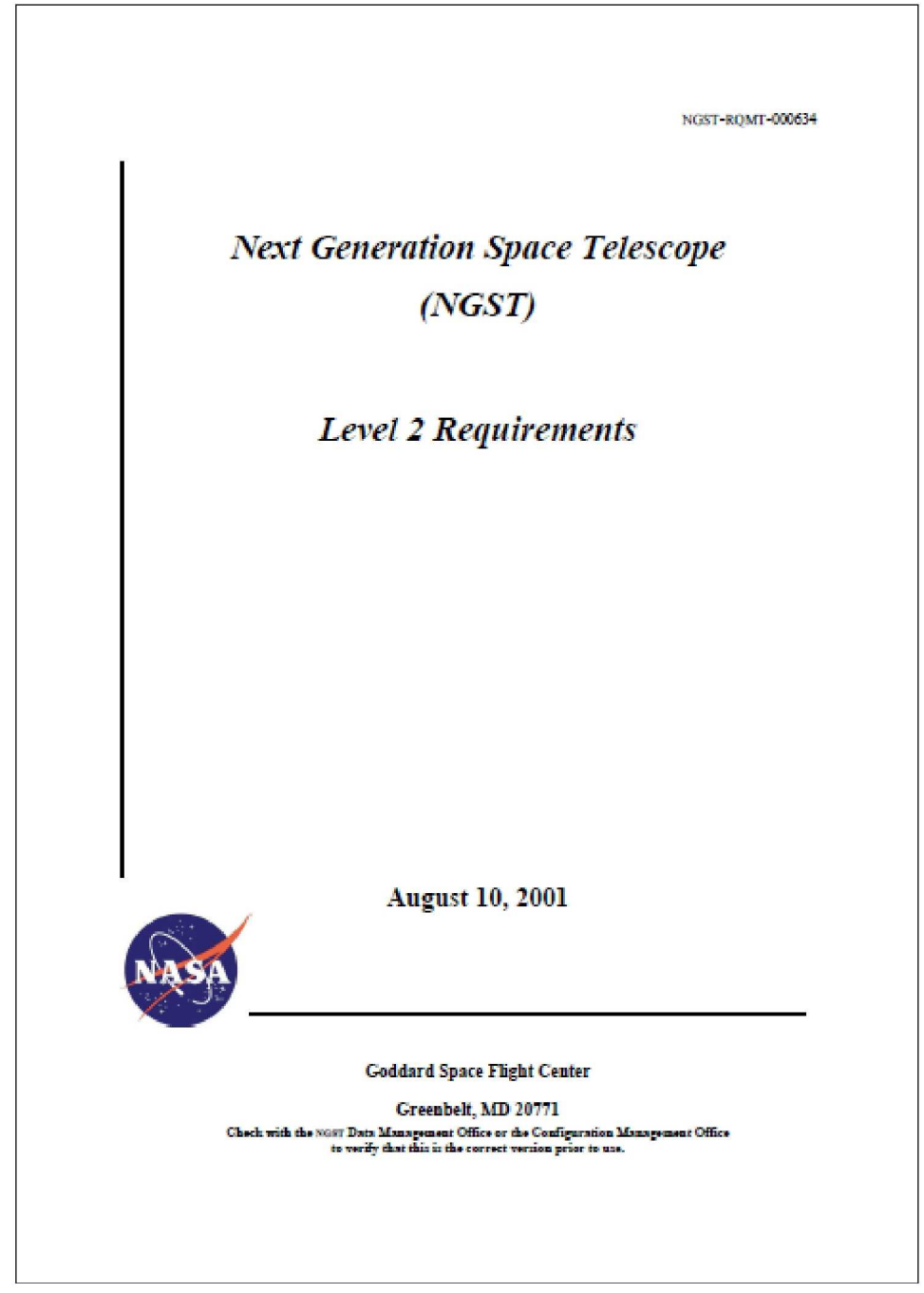
Optical Telescope Element

Primary Mirror Area

The unobscured primary mirror area shall be greater than or equal to 25 square meters.

Wavefront Error Allocation

The OTE shall be allocated 131 nanometers rms of wavefront error.



NGST-RQMT-000634

Next Generation Space Telescope

(NGST)

Level 2 Requirements

August 10, 2001

NASA

Goddard Space Flight Center

Greenbelt, MD 20771

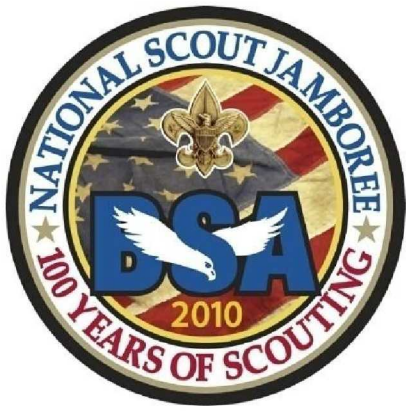
Check with the NGST Data Management Office or the Configuration Management Office to verify that this is the correct version prior to use.

JWST Master Schedule

11/30/09

JWST Master Schedule	2008			2009				2010				2011				2012				2013				2014				2015
	FY08			FY09				FY10				FY11				FY12				FY13				FY14				FY15
	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
Major Mission Milestones	PDR/NAR 3	KDP-II 7						CDR 4												MOR 12	TRR 1	SIR 5	KDP-III 8			PSR 4	FRR KDP-IV 5	LRD 6	ORR 12
Integration & Test	1/3 Scale Sunshield							IDR 9	Fab	Thrml Rev 12		Integ 2			TRR 9	Test			Deprops 1 2	SC Panel Integ 1 5	SC Panel Integ 2 6	CCA, Prop Integ 9	SCE Integ 10	CST 1, Model 11	Subsys Deploy 12	Vib 1	TV 2	Mate OTE / ISIM / IRC to S/C Subsys Deploy 4	CST 2/ EMC 6	Acoustic, Vib, Shock 7	Deployments, CST 3 & Mass Props 10	4 Mgm't Reserve 1	Ship Prep 5	Launch Prep 5	6
OTE								OTE CDR 10				JSC CHA Ready 6				OTE/ISIM Integ Review 5													
JSC Activity	ITT GSE SRR 1		GSE PDA 6			GSE CDA 3						Install GSE 7	Rake-Out 9	Cryo Install Prf Loadwa 10	PF AOS 11	Chamber Comm 12	Install PF w/ Cryo AOS 2	PF Cryo Test 2 4				Ambient 8	10	OTE/Flt ISIM Cryo 2	3 Slack				
SSDIF Activity	GSE SRR 1		GSE PDA 6			GSE CDA 3					SES Ready 10	SSDIF Ready 1	GSE Installation		PF Optics Integ 9	11	Flt Optics Integ	Final Mirror 5		Flt ISIM Integ 5	7	Acous, Vibe CrCl Test 9							
Pathfinder Structure (PF)										PF Struts 3		PF PMRSS 7		PF SM SS 3	PF Struct Integ 4 6														
Flight Structure (PMBSS)						CDA 9						Cry Cyc TRR 10	Cryo Cycle 1	Final Testing 4		OTE Struct Assy 7	MMS ISIM Test 10	11											
Primary Mirrors (PMSA)			Start Flt Cryo Test #1 12			Start Flt Cryo Test #2 9		Start Flt Cryo Test #3 1				PF PMSA 1		#1 4	#2 5	#3, 6	#4 7	#5 7	#6 (Last PM Batch) 8										
Sunshield (SS)																													
Membranes	SS PDR 2				MMS PDA 2																								
Evolutionary Pathfinder (EPF)				Flt Membrane Mat'l Fab Cpt 12			NeXolve 1/3 T/V Membrane Delivery 6		TM Start 10	NeXolve CDR 11	SS CDR 12	Qual Test Complete		UPS MRR 7			Flt Membrane Fab 12			Del L-1 6	Del L-2 8	Del L-3 10	Del L-4 12	Del L-5 1						
Flight Sunshield	EPF-2 Tests 3		9			IVA Set Up & Testing 5		Tooling 1		Flt Checks 10	6			Mfg/Tooling & Test 5						Integ & Test 1		Ship to I&T 6	3 Slack						
Spacecraft (SC)								PDR 7																					
				Structure PDA 12								Structure CDA 6				SC Bus Fab & Assembly 5				Test 9	SC Structure Del 12			Prop I&T 9		Ship Propulsion System to I&T			
SC & IES Simulators	SC Sim for ICDH Lab SC Sim for ISIM SCL 1					ETU ISIM I&T Type 1A 5						IES SCL 9	Flt ISIM (Type 2A) 10		IES EMTB 3				IES OTB 3										
Observatory FSW/EMTB		Bld 1 PDR 2					Bld 1 CDR/ Bld 2 PDR 6					Bld 2 CDR 6	Bld 1 TRR 8				Bld 2.1 TRR 9				Bld 2.2 TRR 7					FSW Del to SC 2		FSW Del to Obs 9	
Build 1 & 2/V&V		B1.3 4					B1 Update 9					B1 Veif 12					B1 Val Start 9	B2.1 Veif 11	B1 Val Cpt 3		B2.1 Val Cpt 10	B2.2 Veif 10		B2.2 Val Cpt 3	Obs Veif 4		Obs Val 9		
ISIM				ISIM CDR 3																									
Integration & Test								Rec Structure from ATK 7	Structure Acceptance Testing			Start I&T 7	OSIM 9			PER 4	Start Cryo 1 5			Start Cryo 2 1		Reserve 6	Del Flt ISIM to OTE 6						
NIRSpec				CDR 10					ETU Del 2		Flt Del 1																		
MIRI									STM Del 1		Flt Del 1																		
NIRCam									ETU Del 2						Flt Del 3														
FGS				TFI/Systems CDR 3					ETU Del 2		Flt Del 1																		
Cooling System	PDR 2						CDR 6					Flt Check CHA 6	Flight CHA 10		EM CTA 1	CCA Mock-up	COBS/ CELS 5 6	Flight CTA 7			Flight CCA/CCE 5	Flight CCA/CCE (spare) 5							
Ground Segment		CCTS B2.1 9			CCTS B2.2 5								S&O C PDR 9	CCTS B2.3 10		S&O C Rel 0.0 6		CCTS B.2.4 10	S&O C CDR 10	S&O C Rel 1.0 12		S&O C Rel 2.0 7		OTB Del 12	S&O C Rel 2.x 1			Start "on call" Support 12	

Rev-I DRAFT



Engineering the Future

Optical Engineering Design Tools

Specialized Software Tools

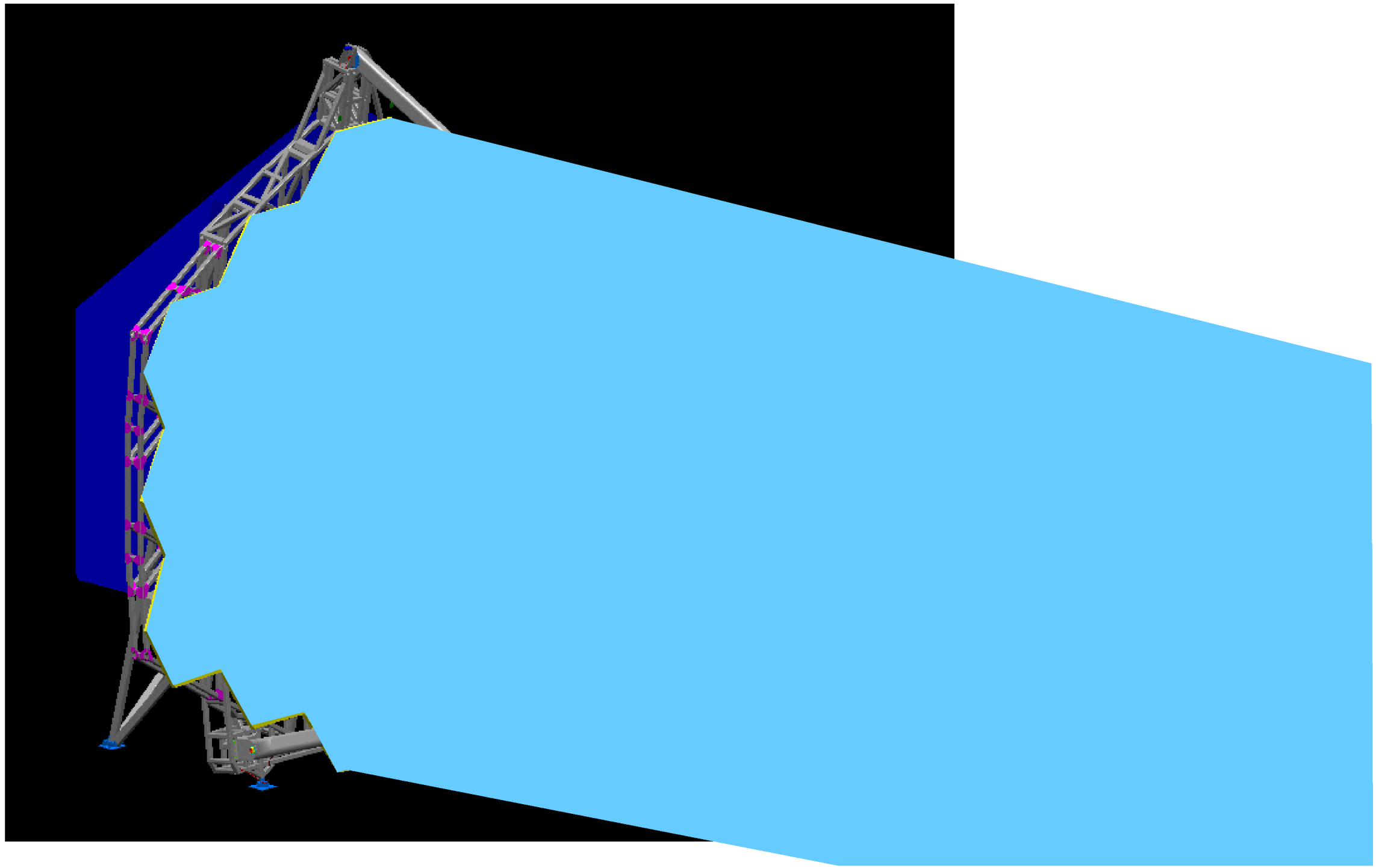
- Optical Design
- Computer Aided Design (CAD)
- Dynamic Response
- Thermal Design
- Straylight

Generic Software Tools

- Word Processing
- Spread Sheets
- Power Point
- Scheduling

Engineering Development Units

JWST Optical Path



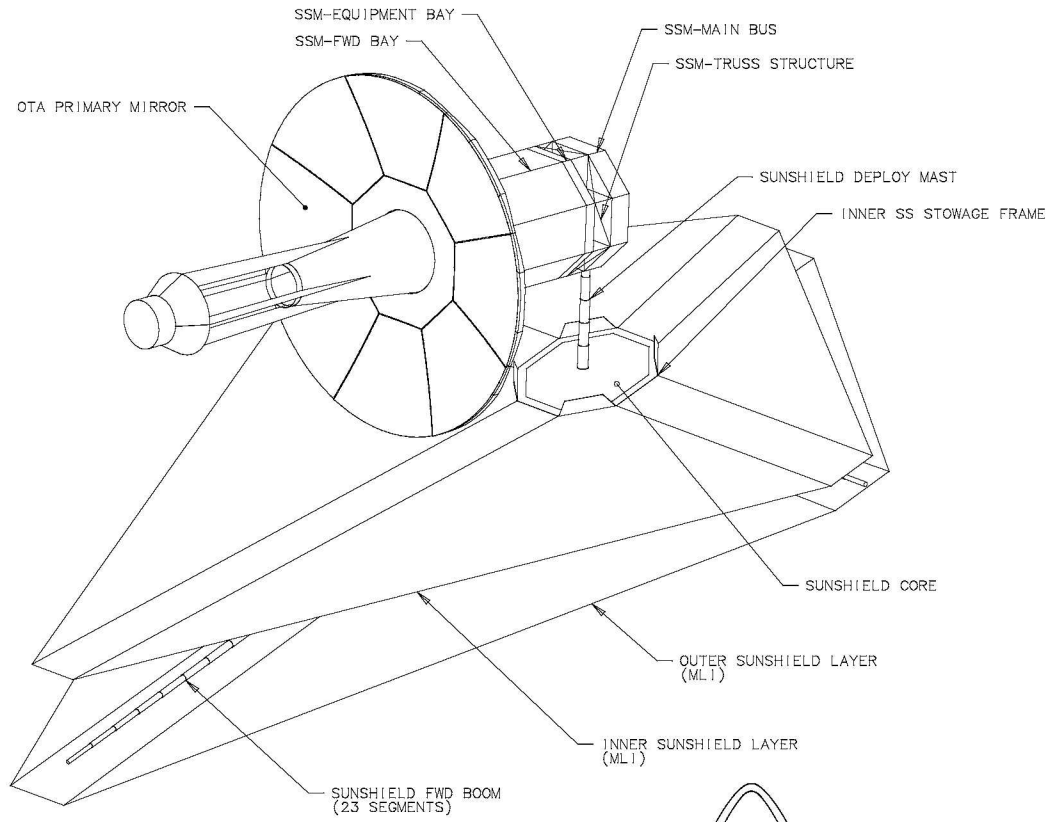
Engineering the Future

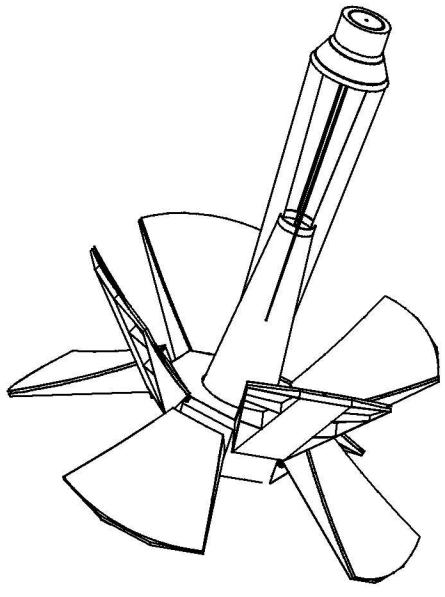
Preliminary Design & Analysis

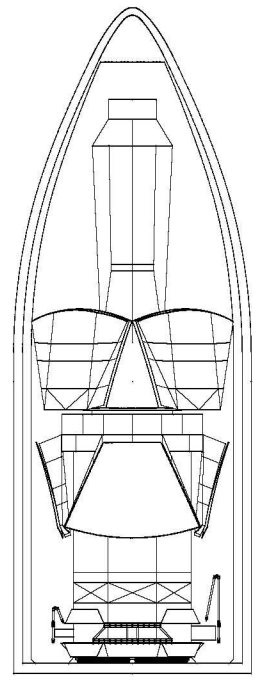
- Space Telescope Missions Take a Long Time to Plan
  - Science Planning for JWST began in 1989
  - Preliminary Design began in 1996
  - Launch is scheduled for 2014
    - 25 years after initial idea
    - 18 years after preliminary design began.
- Because of Launch Vehicle Fairing Size Constraints, JWST must be segmented.
  - JWST Collecting Aperture is 6.5 meters diameter
  - Largest Launch Vehicle Fairing Size is 4.5 meters diameter
- Preliminary Design Contracts resulted in two design concepts
  - These two concepts competed against each other until in 2003 when NASA selected the TRW/Ball concept

Two Competing Design Concepts

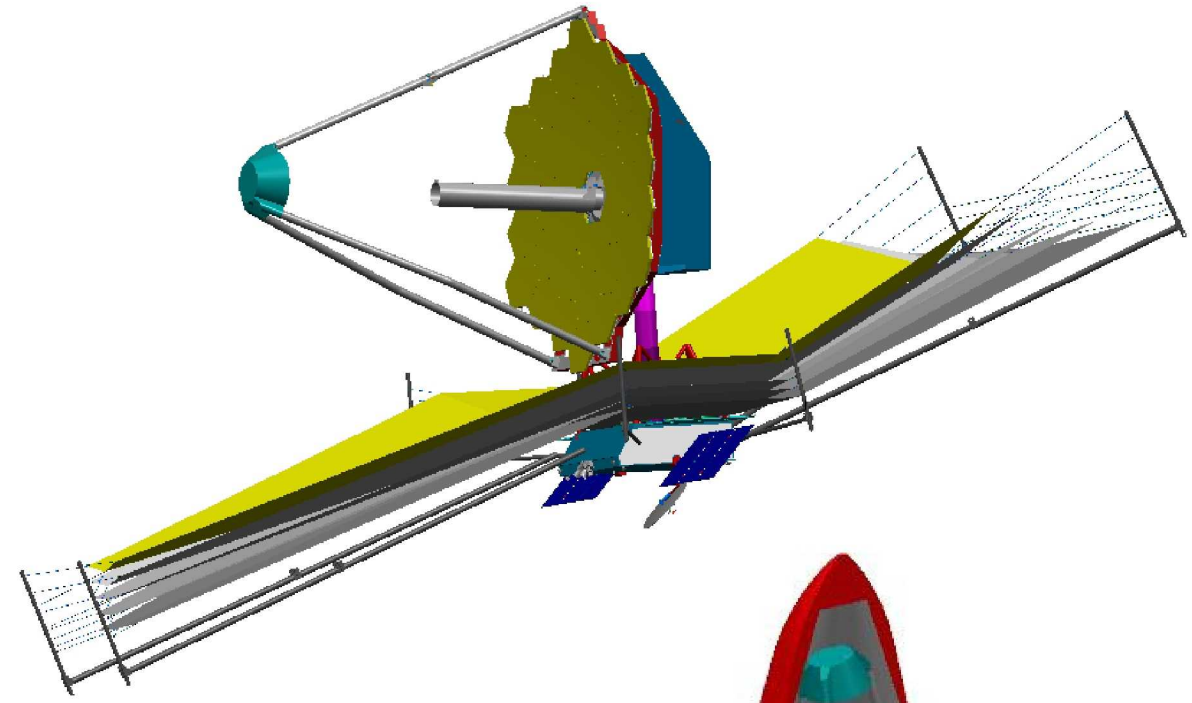
Lockheed/Raytheon

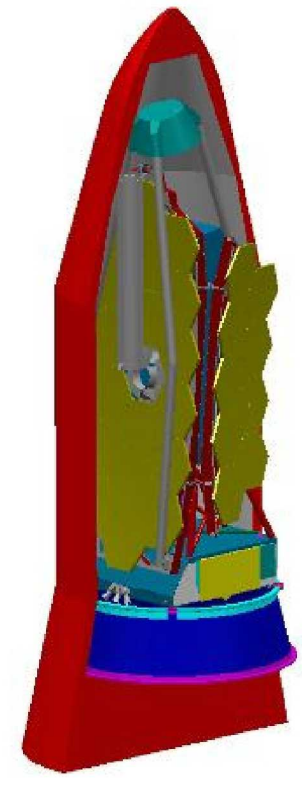




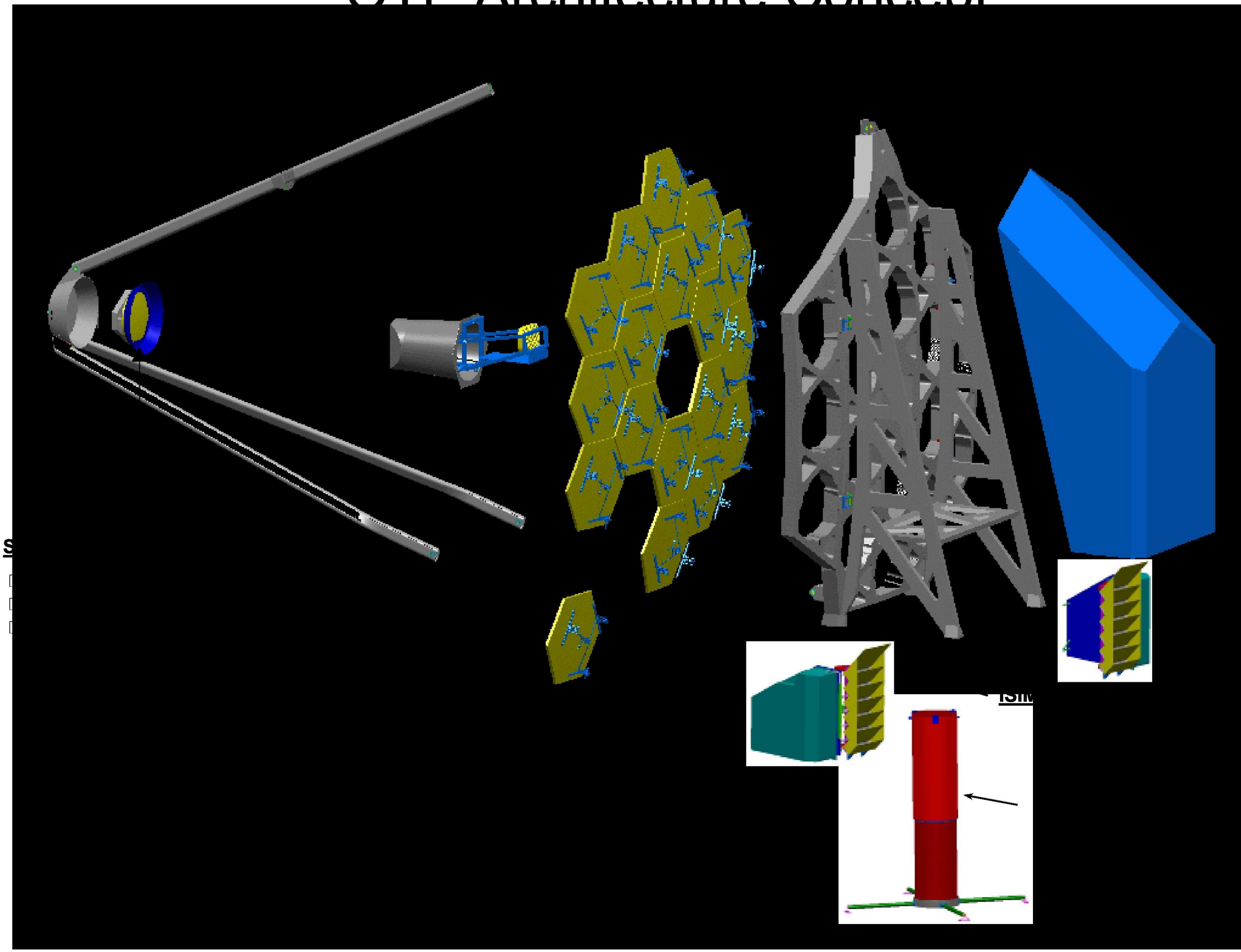


TRW/Ball





OTE Architecture Concept



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ISIM

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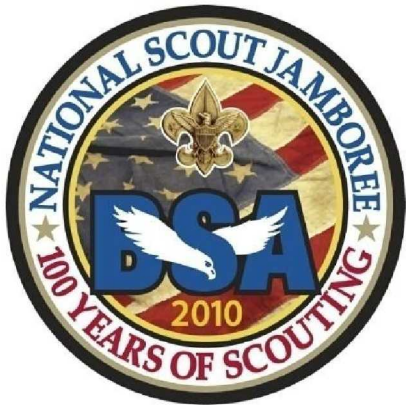


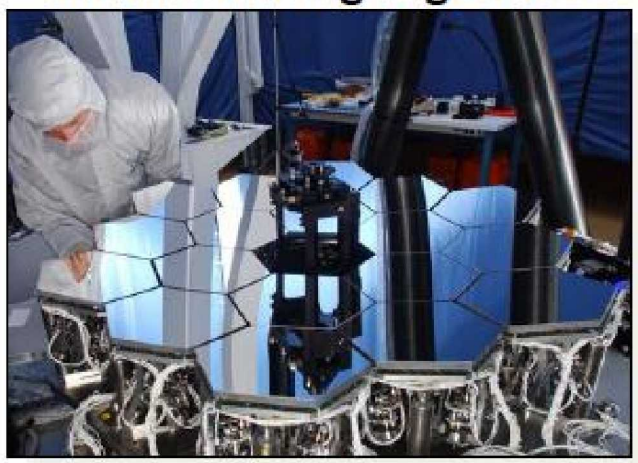
Engineering the Future

Technology Development

- In 1996, the technology did not exist to build JWST.
- NASA invested over $300M in technology development.
- Starting in 1999, it was my job to lead the Mirror Technology Development effort.
- Specific mirror technology that had to be developed:
  - New kind of Beryllium alloy
  - New ways to manufacture mirrors
  - New ways to test mirrors
- Same as for the observatory concepts, there was a competition between mirror technologies and eventual selection.

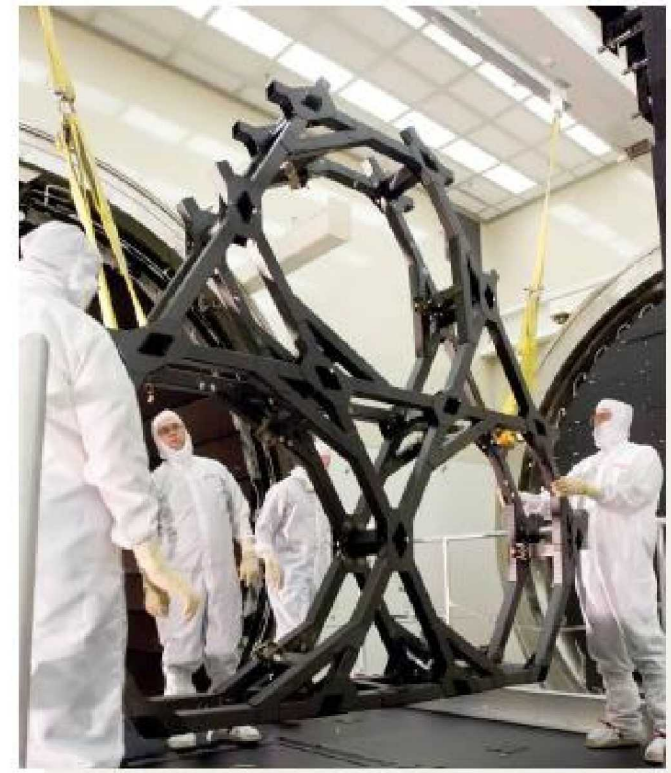
JWST Technology Demonstrations for T-NAR

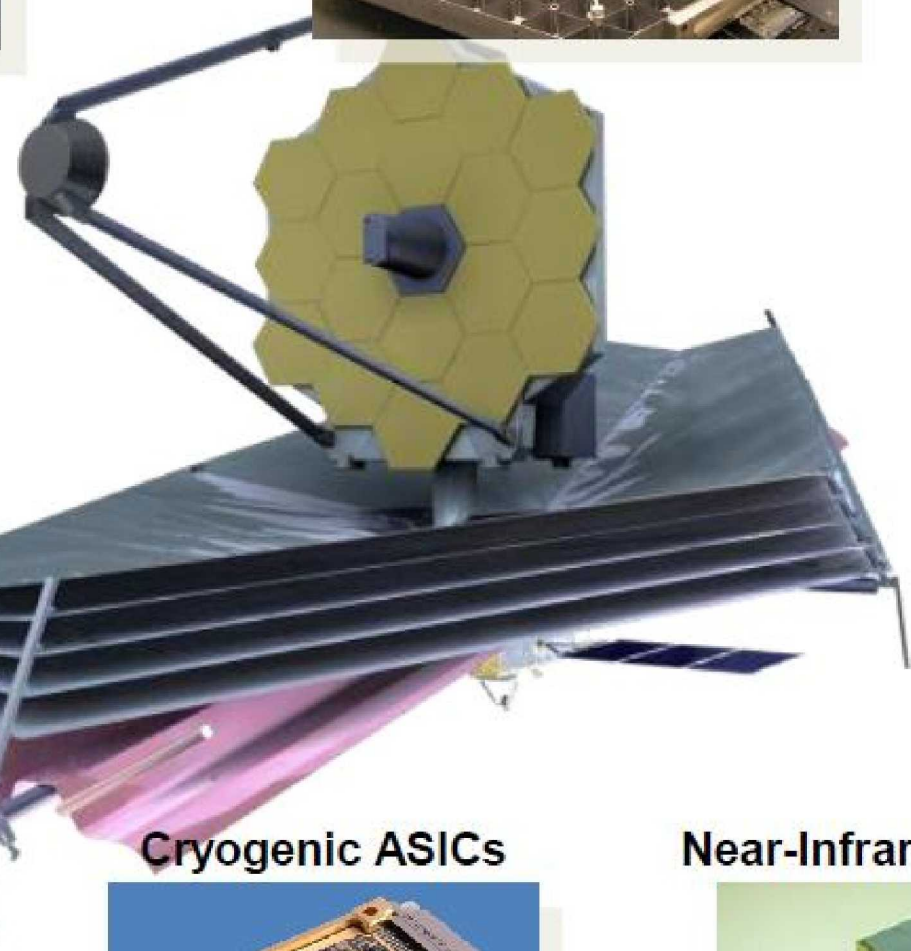
Mirror Phasing Algorithms



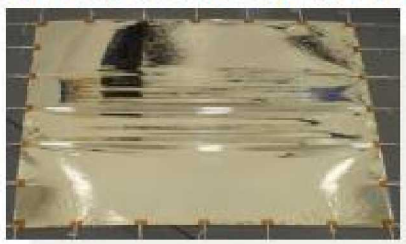
Beryllium Primary Mirror Segment

Backplane

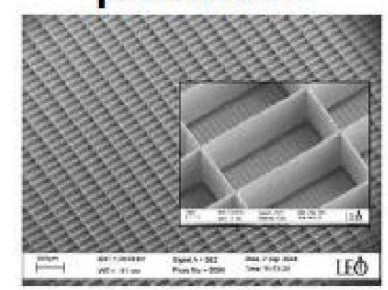




Sunshield Membrane

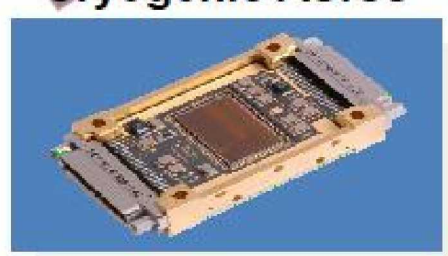


µShutters

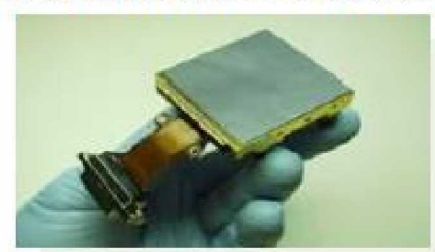


Cryocooler

Cryogenic ASICs



Near-Infrared Detector



Mid-Infrared Detector

Investments Have Reduced Risk

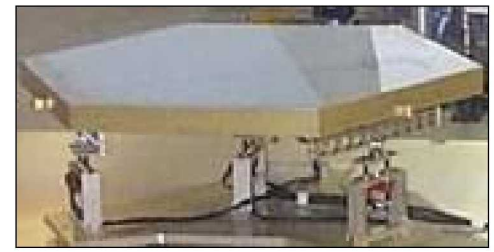
Mirror Actuators

Mirrors

AMSD

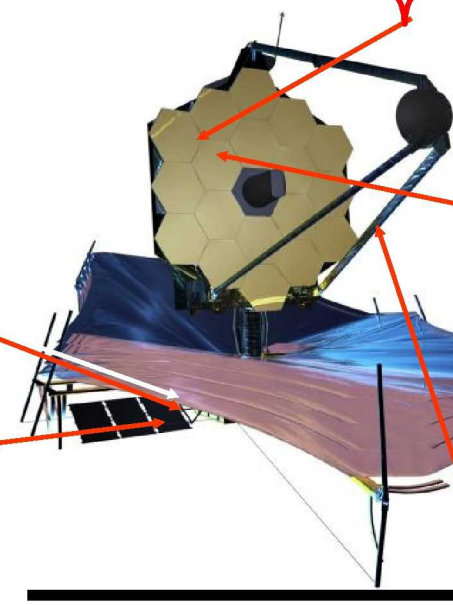
SBMD

Mirror System



Wavefront Sensing and Control, Mirror Phasing

1 Hz OTE Isolators



ic Deployable Optical
pe Assembly (**DOTA**)

Reaction Wheel Isolators

Half-Scale Sunshield Model

Secondary Mirror Structure Hinges

Primary Mirror Structure Hinges and Latches

JWST Mirror Technology Histor

NAR

Areal Density (Kg/m²)

30
20
10

1980 1990 2000 2010

SBMD

JWST Requirement

2006

2004

JWST Mirror Risk Reduction

TRL 6

text

JWST Primary Optic Technology Selected - TRL 5.5

text

Complete vibro-acoustics Test

text

JWST Prime Selected

2000

AMSD Phase 2

1998

AMSD Phase 1

SBMD

Onset NGST 1996

SIRTF Monolithic Manufact

- NASA HST, Chandra, SIRTF Lessons Learned
  - *TRL 6 by NAR*
  - *Implement an active risk management process early in the program (Early investiment)*

Mirror Material/Technology Selection, September, 2003

- Beryllium chosen for technical reasons (cryogenic CTE, thermal conductance, issues with glass, stress issues with Be noted)

Prime Contractor Selection

- *Ball (Beryllium) and ITT/Kodak (ULE) proposed as options, Goodrich dropped from AMSD*

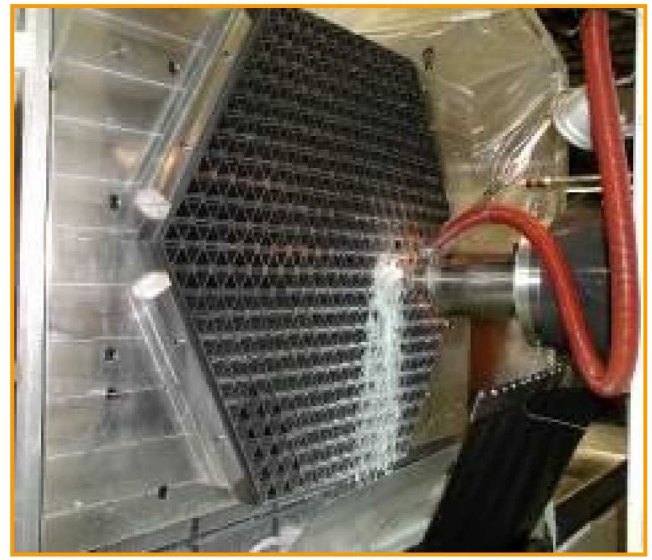
Pl ... ld .5 meter demonstrations)

Based on lessons learned, JWST invested early in mirror technology to address lower areal densities and cryogenic operations

Mirror Manufacturing Process

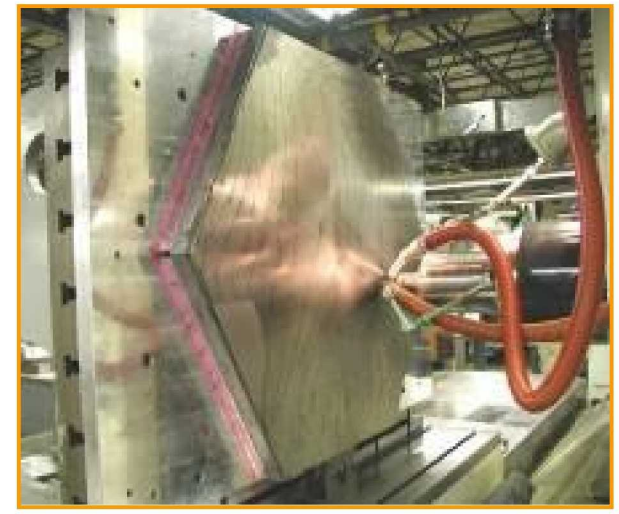
Blank Fabrication

HIP Vessel being loading into chamber



Machining of Web Structure

Machining



Machining of Optical Surface

Completed Mirror Blank

Polishing

Mirror System Integration

Engineering the Future

Engineering Development Units (EDUs)

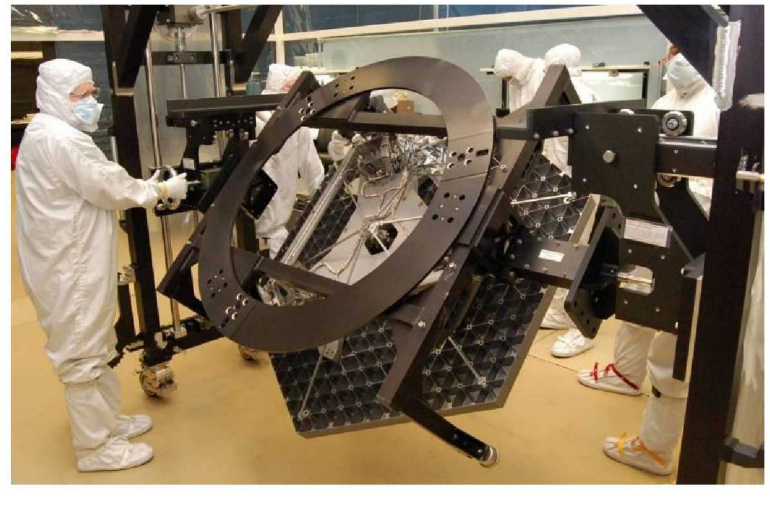
EDUs are extremely important.

Flight Hardware is VERY EXPENSIVE

EDUs allow us to practice how to manufacture, handle, test, and assemble the flight hardware.

EDUs allow us to make mistakes without the risk of damaging the flight hardware.

JWST EDUs and Simulators



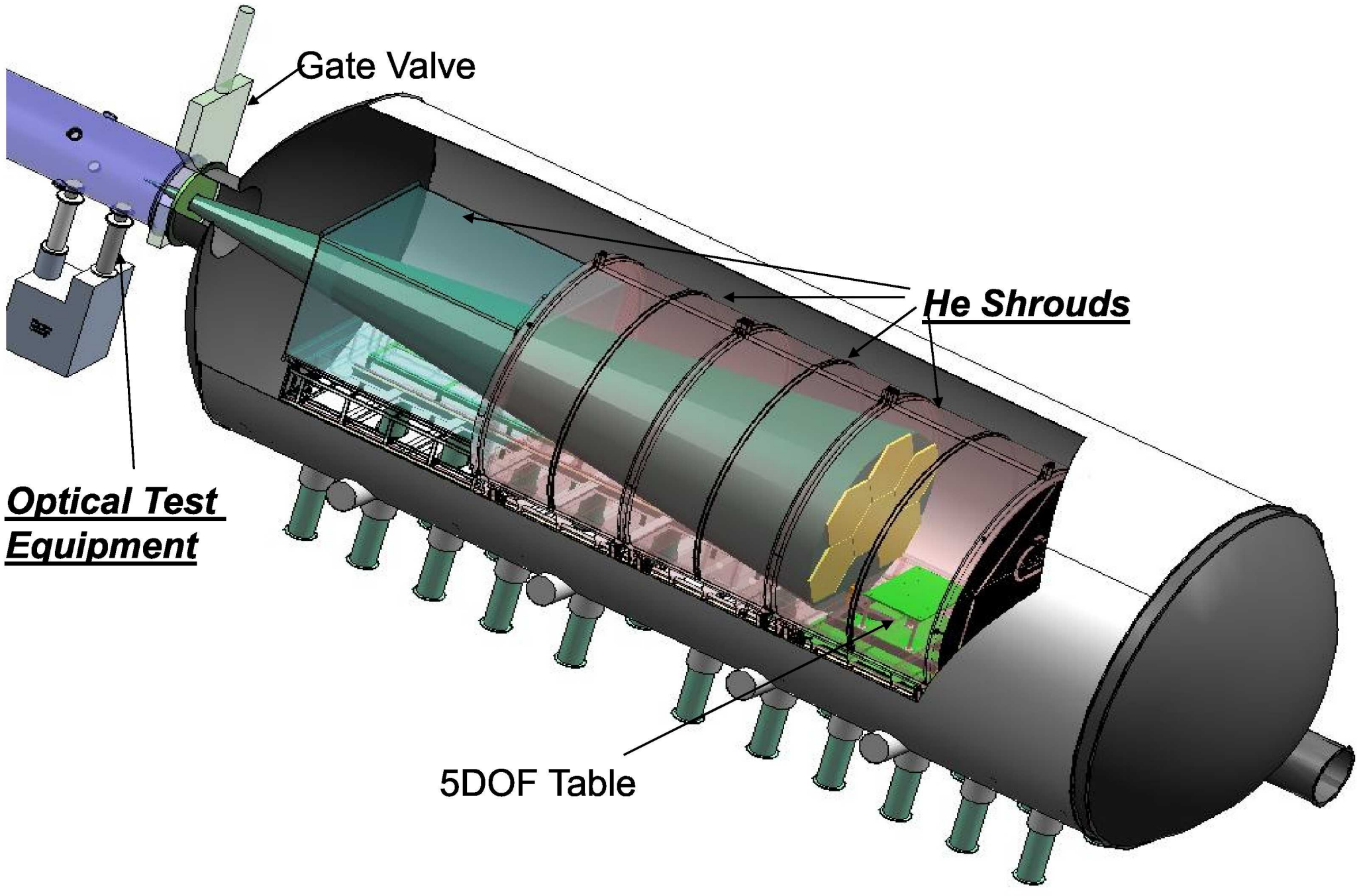
Engineering the Future

Verification & Validation by Test & Analysis

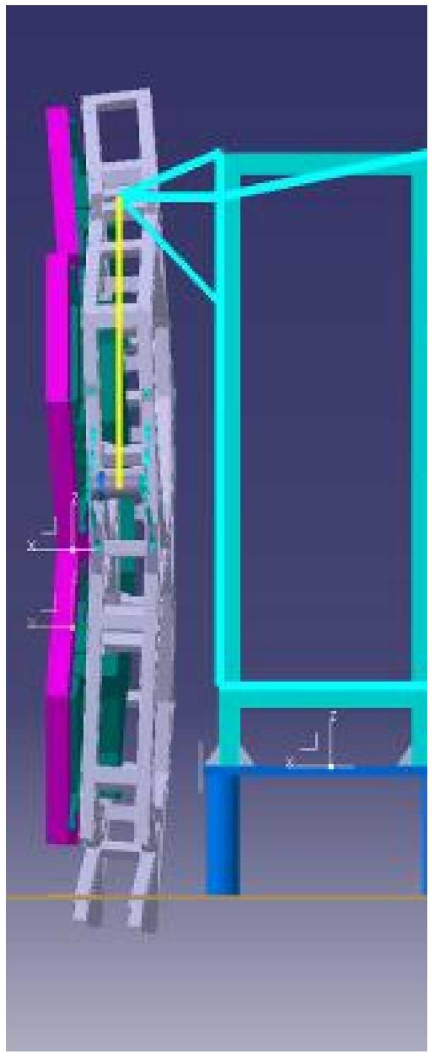
Testing is performed at every level of the program:

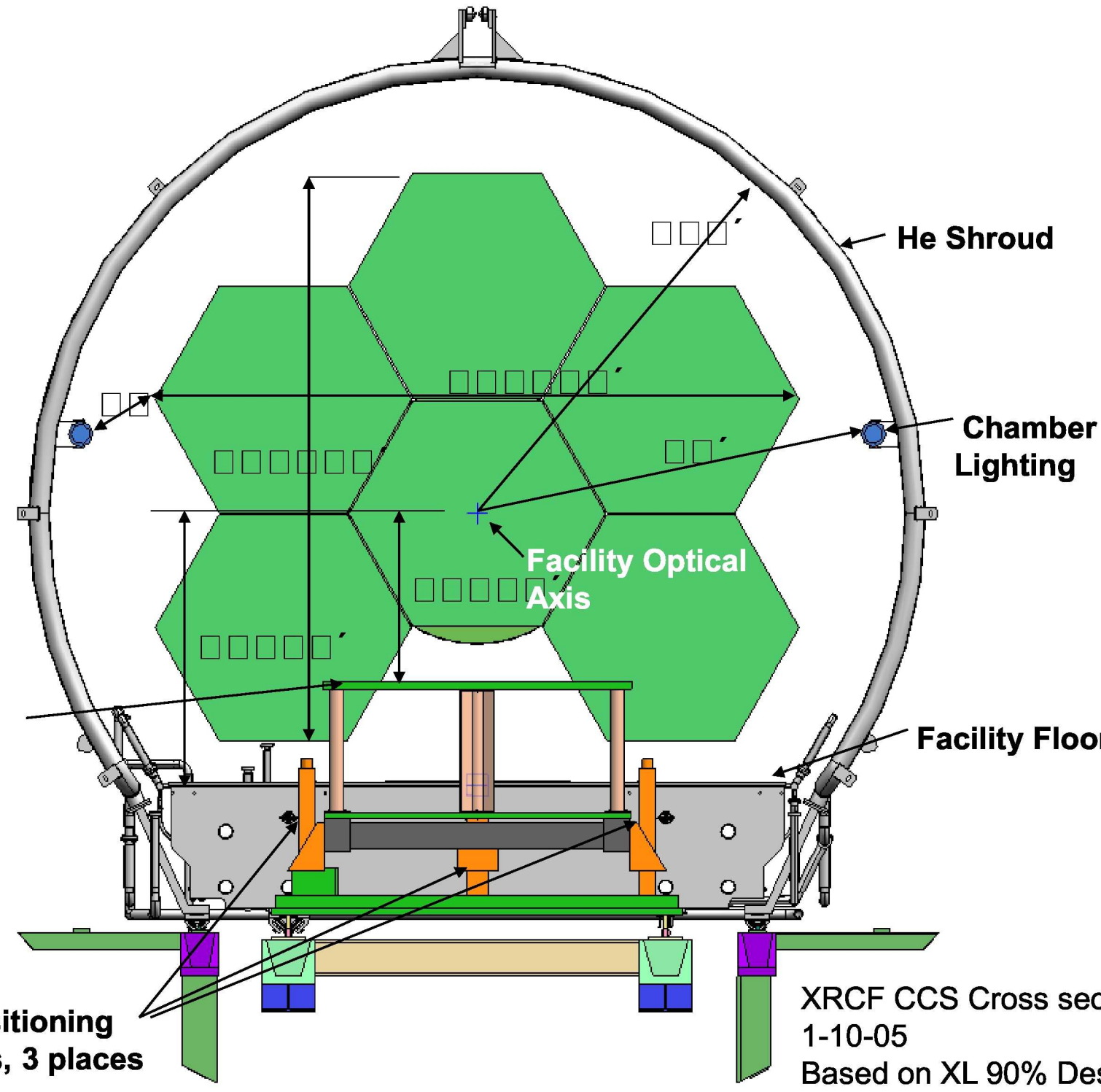
- Component
- Sub-System/Sub-Assembly
- Assembly
- System
- Observatory

MSFC Cryogenic Test Facility



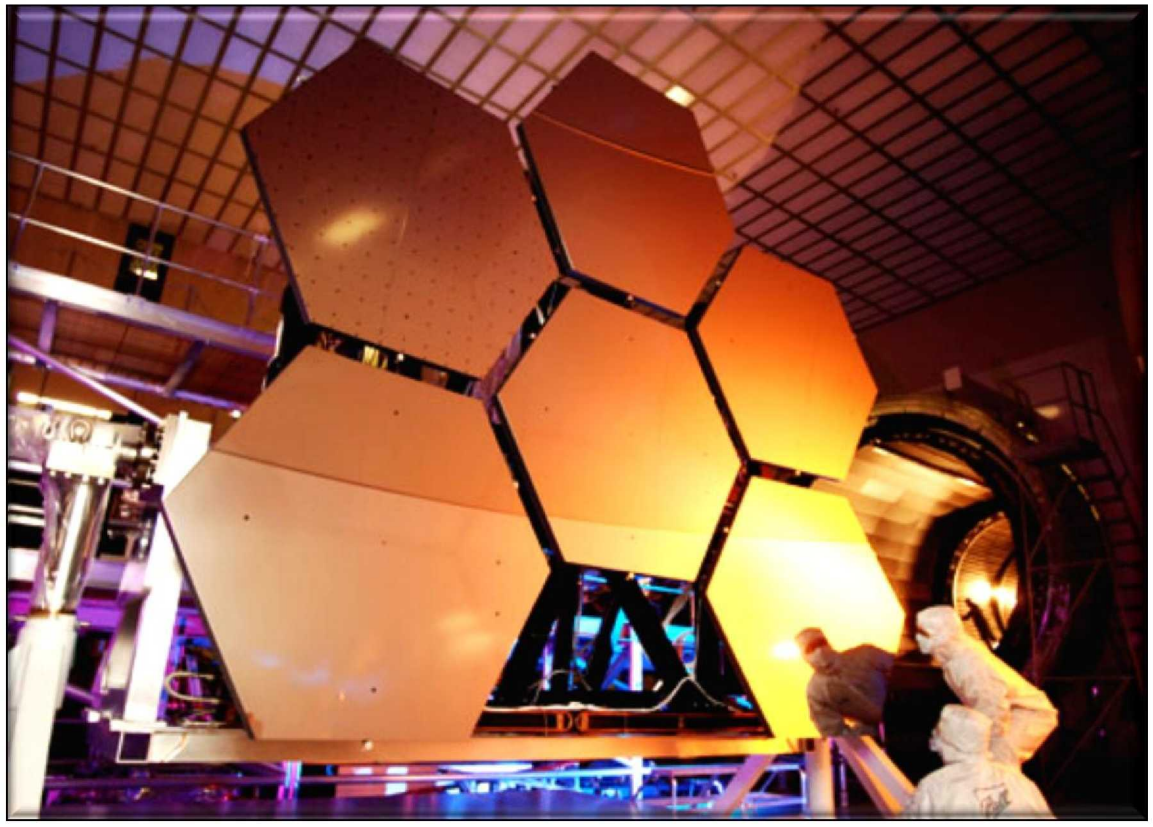
MSFC Cryogenic Test Stand

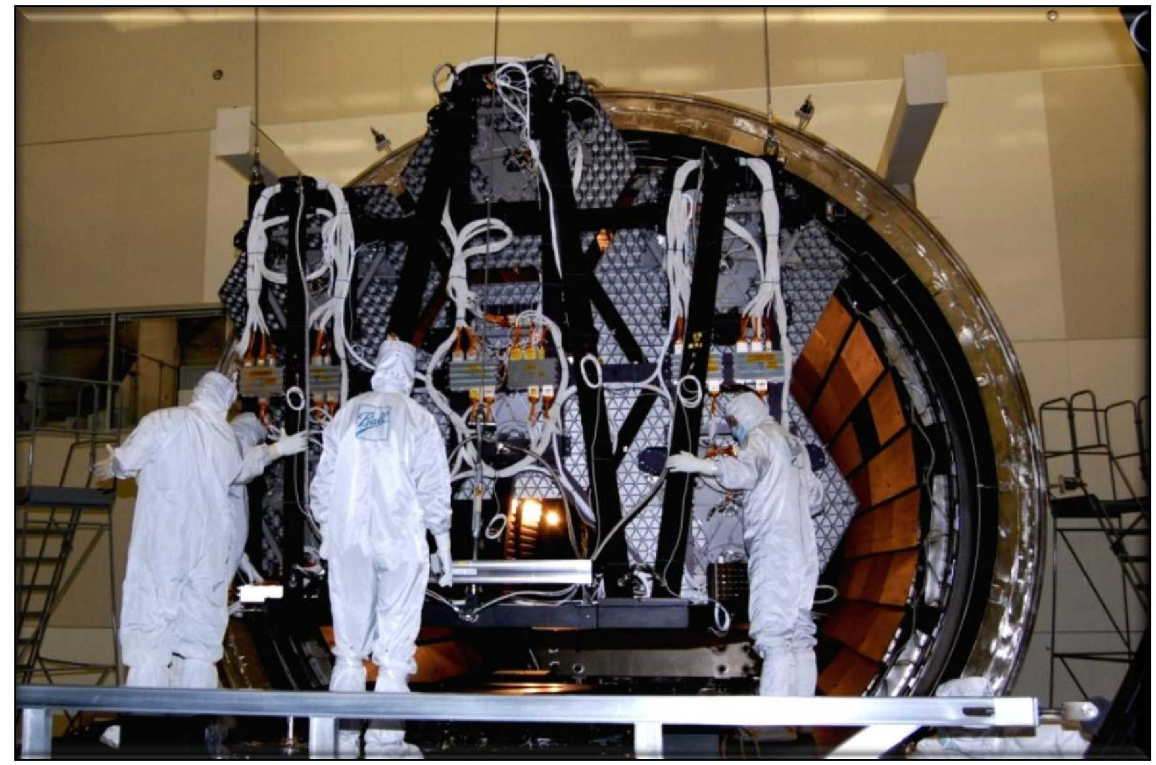


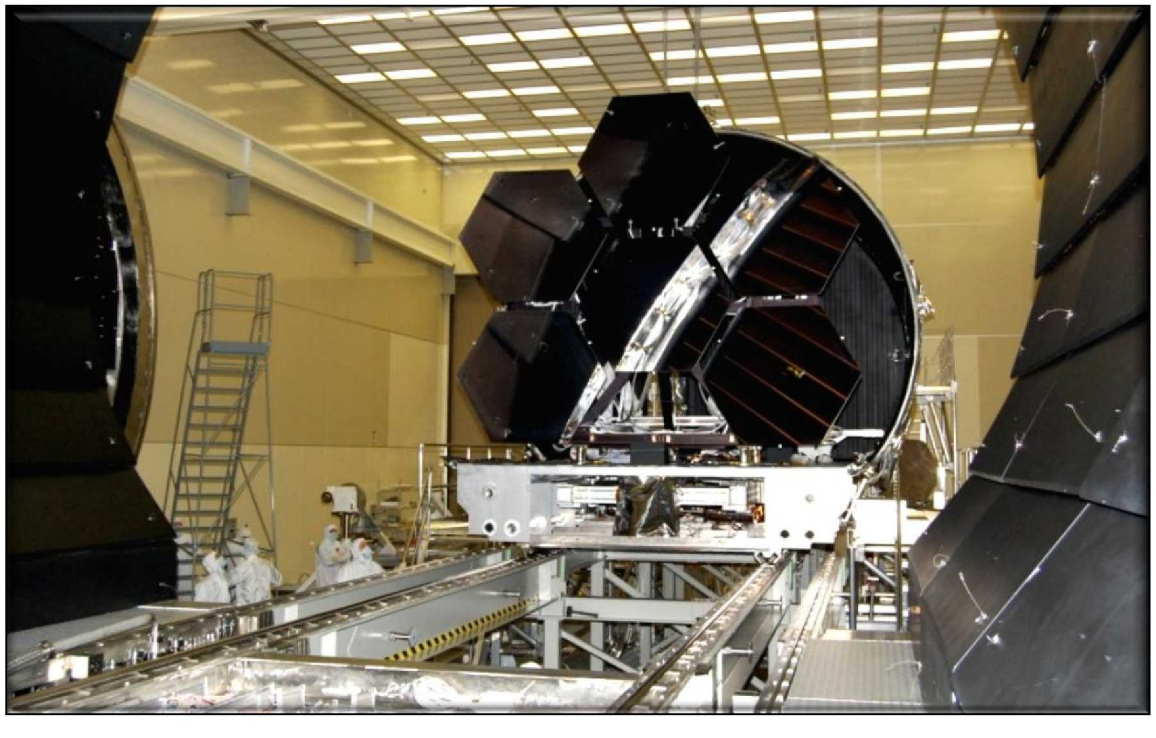


XRCF CCS Cross section
1-10-05
Based on XL 90% Design Review Data

Primary Mirror Cryogenic Tests

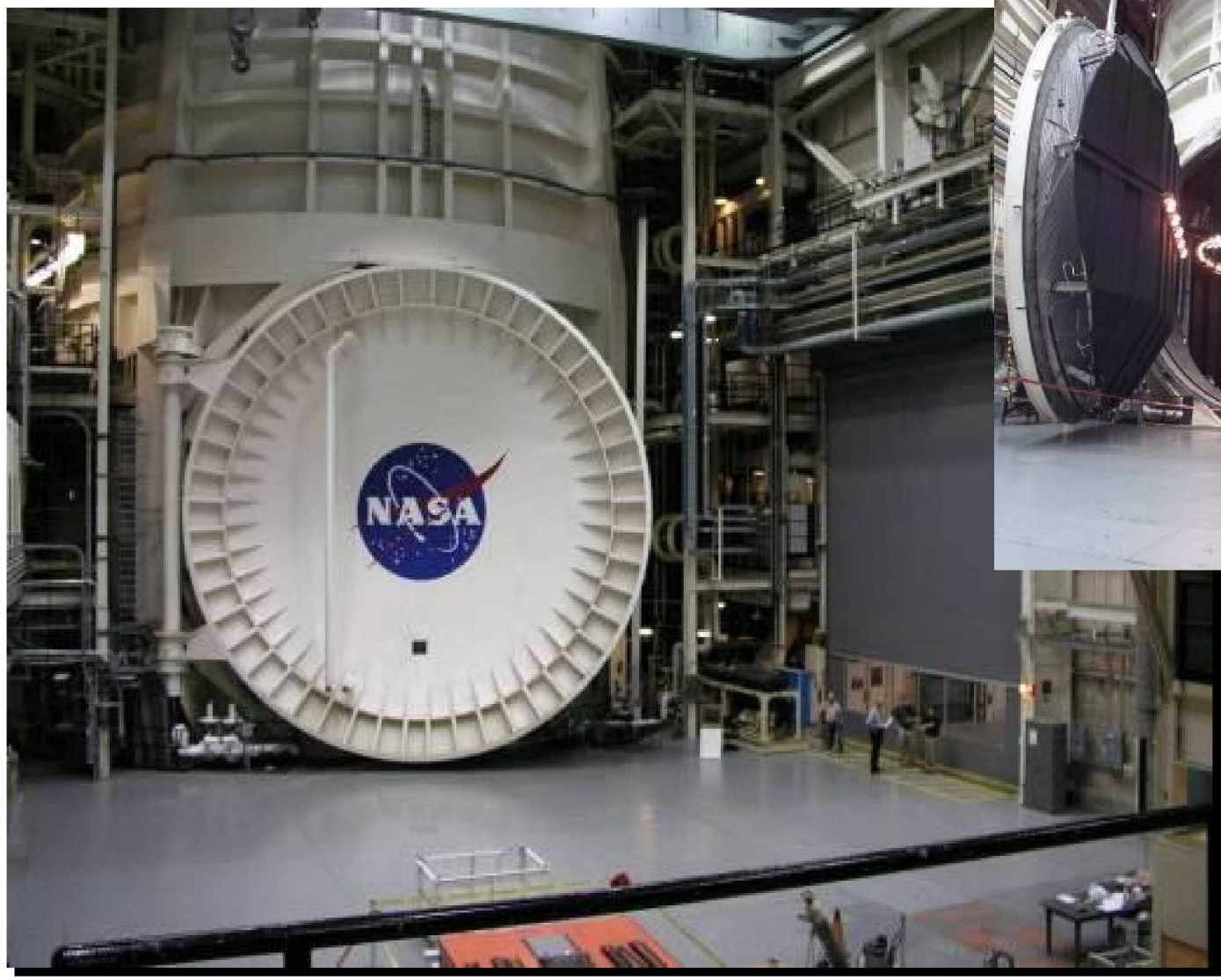


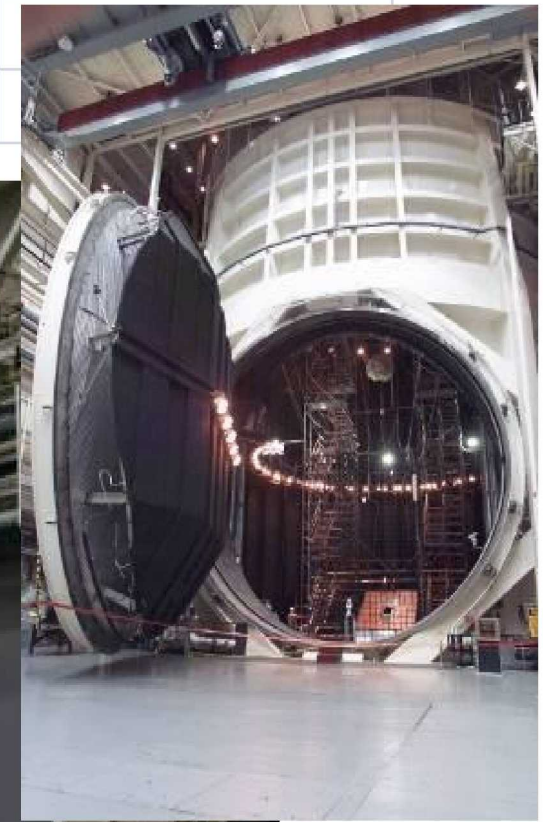


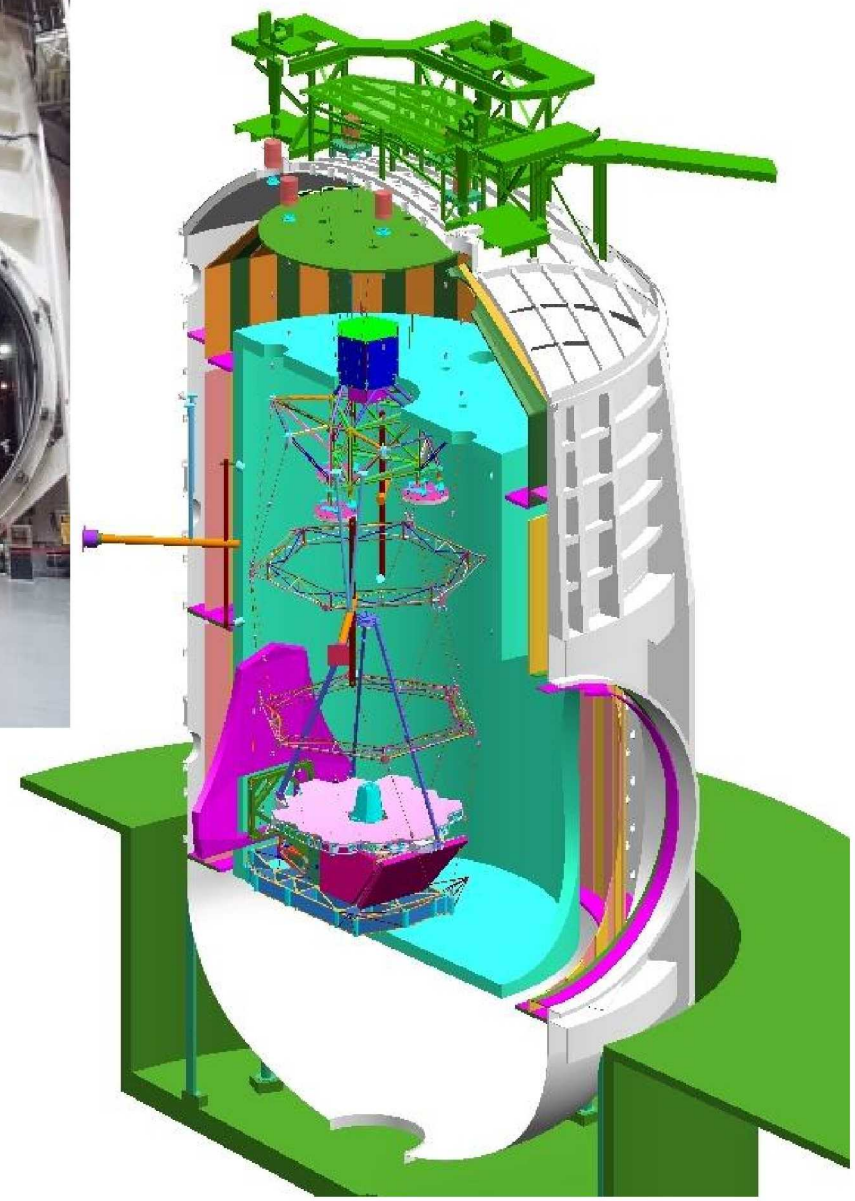


JWST Observatory Level Integration & Test

Johnson Space Center Chamber A	
Chamber size	16.7 meter diameter, 35.6 meter tall
Existing Shrouds	LN2 shroud, GHe panels
Chamber Cranes	4 x 7.6 meter fixed, removable
Chamber Door	12 meter diameter
High bay space	~31 m L x 21.6 m W







JWST vs. HST - orbit

NORTHROP GRUMMAN
Space Technology

Sun

Earth

Moon

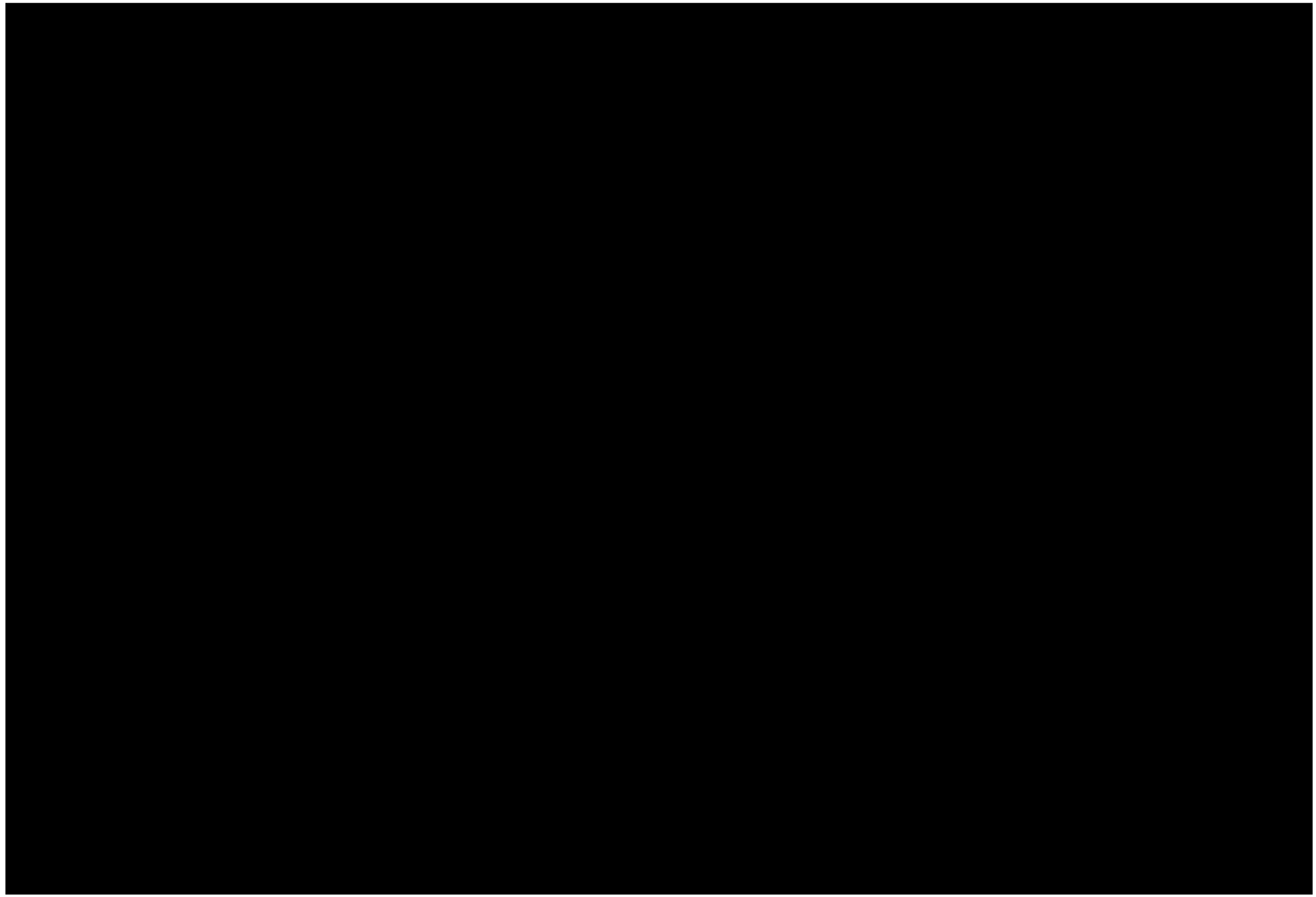
HST in Low Earth Orbit, ~500 km up.

Imaging affected by proximity to Earth

L2

JWST will operate at the 2nd Lagrange Point (L2) which is 1.5 Million km away from the earth

JWST Deployment Movie



Any Questions